DISCOVERING THE ATOM

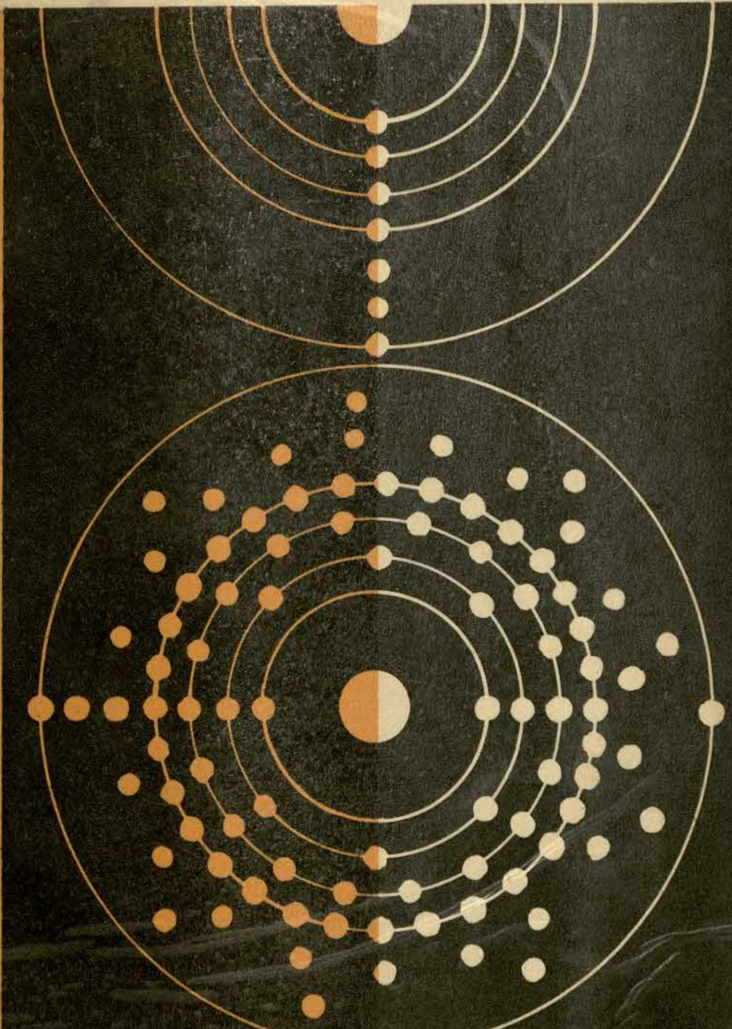

diagram showing the structure of the plutonium atom

D. W. HUTCHINGS

THE DISCOVERY REFERENCE BOOKS

General Editor:
ALYS L. GREGORY, M.A., Ph.D.

DISCOVERING THE ATOM

2022

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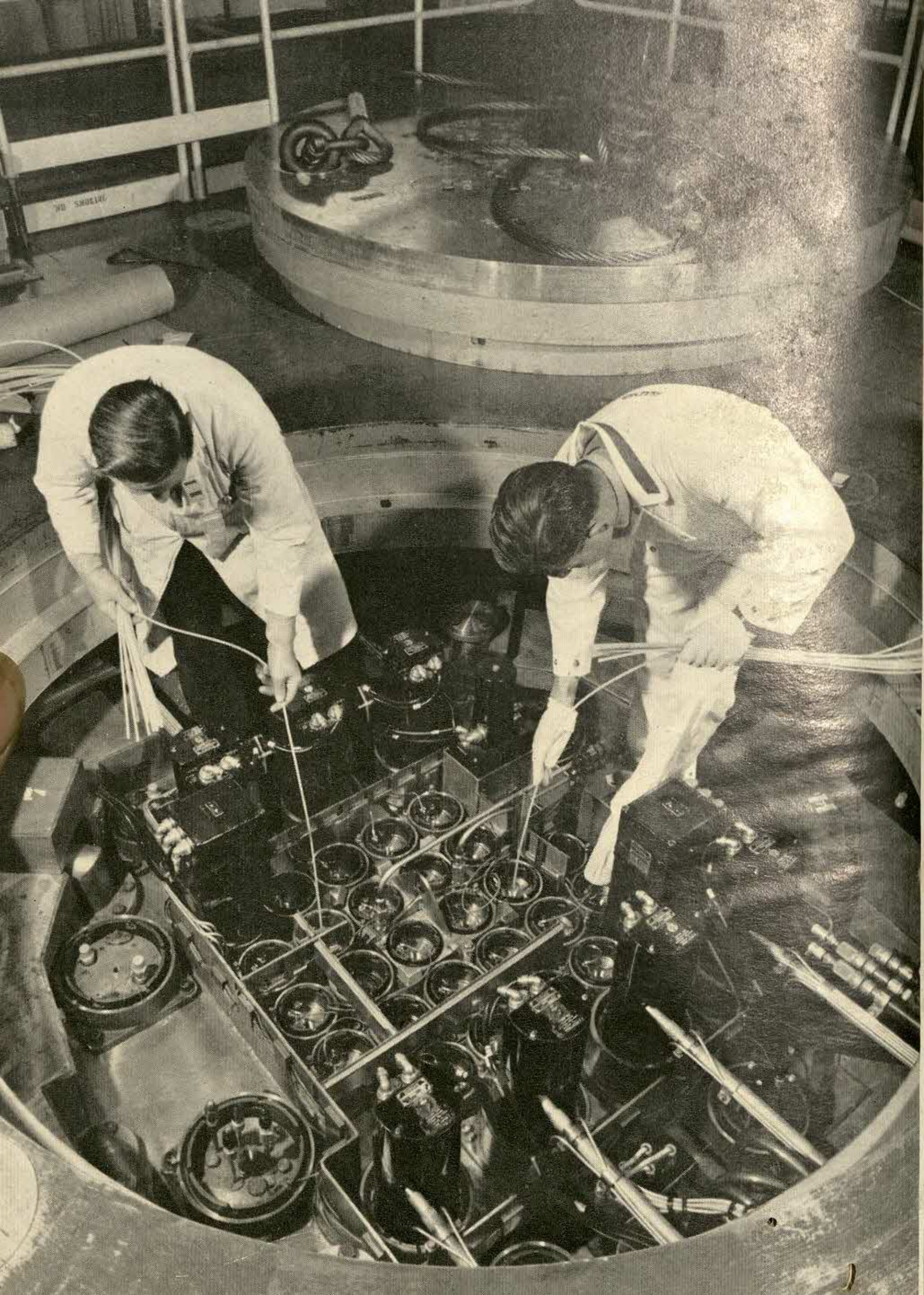
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DISCOVERING THE ATOM

Donald W. Hutchings

2022

With Illustrations by
Malcolm Carder and Terence Freeman

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FOREWORD

Atomic power, the most exciting discovery of the twentieth century, has opened up undreamed-of possibilities to mankind. This book has been written to help young people to understand the new forces which make this the Atomic Age.

In Part I you can read the stories of the discovery of radio-activity and of the splitting of the atom by modern scientists, of the first atomic bomb and of the first voyage under the polar ice-cap by the first atomic submarine, a voyage no ordinary ship could undertake.

In Part II you can learn what atoms are composed of and about the different kinds of atoms which make up the various elements and metals. You can read about the scientists who made these discoveries and you can follow their experiments with the aid of very clear drawings and diagrams.

You can also learn how scientists smash atoms today in the great atomic power stations which have been built in the last few years; some fine photographs show them at work. You can learn about the wonderful possibilities of the peaceful use of nuclear power in industry and in medicine, for communications and transport, as well as how an atomic bomb works. There is a list of scientific terms to help you, a table of elements old and new—the new ones created by physicists in the process of their work! —and a list of some of the chief atomic scientists and their discoveries which made all these new developments possible.

Atomic power is the key to the future; this book is intended to help you towards an understanding of that future, so that you can make it your own as a citizen of the Atomic Age.

ALYS L. GREGORY

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PART I

IN SEARCH OF THE ATOM

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CHAPTER I

SECRET MISSION

A Super-Fortress was flying through the night. The pilot checked his instruments: altitude 39,000 feet, air-speed 400 miles per hour, on a steady course for Japan. He looked round the cabin. The navigator was busy with his charts and the radio operator, in his shirt-sleeves, was seated comfortably as he adjusted the controls of his apparatus. The pilot felt reassured as in his mind he compared the interior of the B.29 with that of a smaller bomber. More than seven miles up, it should be freezing cold and difficult to breathe, but the Super-Fortress was pressurised and heated so that the crew could work in comfort.

The navigator looked up.

"Dead on course, sir," he said. "I guess it will soon be getting light."

The bomb-aimer got up out of his seat, walked across the cabin and back to stretch his legs and then sat down again. There was nothing to do but wait. He felt strangely nervous. One bomb on one city—it should be easy, but it didn't feel normal after the mass raids on Kure, Iwakune and Tokuyama. The bomb seemed ordinary enough, and not so big, either. He listened to the steady roar of the B.29's four engines and wondered if there would be much flak over Hiroshima.

The pilot peered out through his windscreen, scanning the horizon: just darkness, stars above with a few faint wisps of cloud, and the ocean below. Then, as he had expected, he saw a very faint streak of light on the eastern horizon. This was the dawn for which they had waited so impatiently. It would not be long now before they would be able to see the thin grey outline of the coast of Japan. Gradually the stars faded and the early morning sunshine illuminated the interior of the plane.

Expertly the navigator surveyed the scene beyond and below. A long group of islands, dark green fringed with white surf, lay away to starboard. He noted the position with satisfaction; right on course and right on schedule. It was not the first time he had seen these islands, but they looked particularly friendly and inviting on this early summer morning. It was odd to think of war on a beautiful day like this. It would be a fine morning in Japan and the people of Hiroshima would soon be getting up to go to work. He looked around at his comrades. They were excited, but they were not talking much. The bomb-aimer was trying to relax in his seat in the plexiglass "blister". How could they relax? he asked himself; they had been waiting for this special operation for weeks. The scientists and the briefing and security officers at the Mariana base had made some pretty stupendous claims for this bomb they were going to drop. He shrugged his shoulders and tried to interest himself in his instruments. The B.29, like a gigantic silver bird in the morning sunlight, flew steadily on.

Quite suddenly, a wave of excitement passed from man to man: the coastline ahead was enemy territory. The gunners were alert in their little turrets as they fidgeted with their guns. This was no time to be caught napping by an enemy "Zero" fighter. They were over the coastline now. The bomb-aimer looked down.

Below, Japan looked very quiet and peaceful; there was no apparent activity on the ground. The silvery B.29 seemed to be unnoticed as it flew on towards the target area.

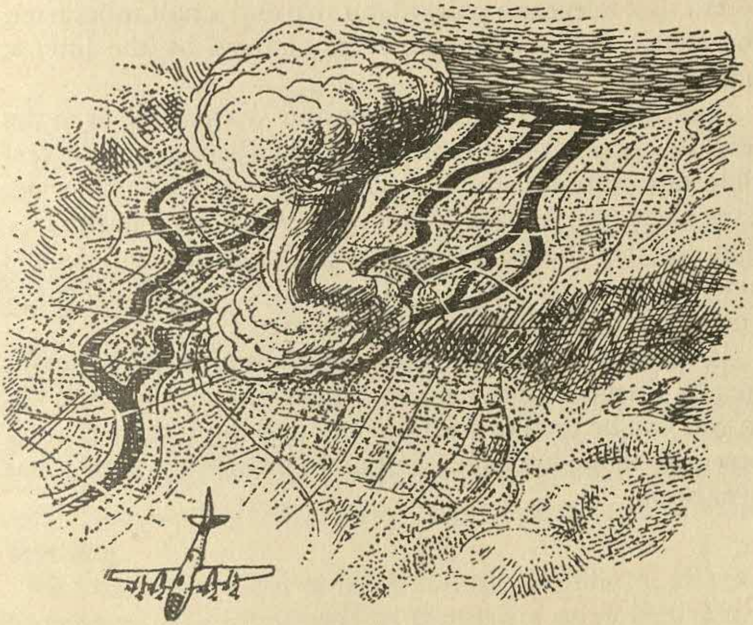
Hiroshima lay between a rim of mountains and the sea. From this height it appeared fan-shaped, as it was built mainly on the six islands formed by the seven mouths of the Ota river. The bomb-aimer looked for the docks and the airport which lay to the south. In an ordinary raid, these would probably have received his special attention. The order came for the crew to put on the thick welders' glasses with which each man had been supplied. Now he could see nothing outside and could scarcely see around him.

The bomb-aimer removed his welders' glasses temporarily and waited anxiously for the precise moment to release the bomb. He received the final check of altitude, air-speed, direction and force of wind; visibility was perfect, no flak to bother about....

"Bomb away, sir!" he cried as he pressed the trigger.

The great plane flew on. The crew members sat quietly and expectantly, listening, watching, waiting—hardly daring to breathe. The engines roared rhythmically, effortlessly. The navigator watched the second-hand of the chronometer tick round in even, unhurried jerks: fifteen seconds—thirty seconds—forty-five seconds: the plane would have covered six or seven miles already. One minute —one minute, fifteen seconds—one minute, thirty seconds: he wondered how much longer.

Suddenly a dazzling flash, brighter than the sun, made the inside of the plane so bright that every detail could be seen, even through the welders' glasses. What sort of man-made flash, fifteen or more miles away, could make the sunlight seem dim? All eyes turned to the source of the incredible glare. A tremendous ball of fire, several hundred yards across and dazzlingly white hot, was shooting up into the sky; as it ascended, it seemed to draw up after it a terrifying tail of smoke, dust and destruction. Gradually, as they watched in awe, the great ball of fire grew darker in



colour and spread out into a swirling, evil cloud like a gigantic deadly mushroom.

It was some days before the extent of the damage to Hiroshima was known. Immediately after the bomb had exploded on that fateful morning of 6th August, 1945, it was evident that the destruction in the city was beyond all living experience. A single atomic bomb, and a small one at that, had had an effect similar to the simultaneous explosion of 20,000 tons of high explosive. It was estimated that about 100,000 people were killed by that one explosion—more than the population of a town the size of Cambridge. Another 40,000 people were injured. More than two-thirds of the buildings in Hiroshima were destroyed and thousands more were damaged beyond repair. It was found that telegraph poles about two and a half miles from the centre of the explosion were charred by the intense heat.

Statesmen and ordinary men and women all over the world were shocked and frightened by the news of the terrible devastation caused by this single atomic explosion. Ever since, the peoples of the world have lived in the fear that one day the final catastrophe would happen. As one newspaper writer put it: "The atomic bomb means the end of war or the end of the human race."

If men can agree to settle their disputes by peaceful means, then the atomic power which can mutilate and kill in war can be used to treat diseases and to produce enough power to make life easier and more prosperous than it has ever been.

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CHAPTER II

THE STRANGE DISCOVERY

One cold evening in 1897, Professor Henri Becquerel walked briskly down a Paris boulevard. The streets were almost deserted. He pulled his overcoat collar more closely round his chin and quickened his pace. He thought of the people sitting in easy chairs in the warmth of their homes, but soon, putting such thoughts out of his mind, he began to think about his experiments with X rays. He was determined to find out more about these strange, invisible rays which seemed to have the power of penetrating almost anything.

He stopped in front of the University buildings; all was in darkness. He let himself in through a small side door, groped his way up some steps and along the corridor at the top. Professor Becquerel could have found his way blindfold to the Chemistry Department—as he often jokingly told his friends, "Just follow your nose!" At the end of the corridor, he took a bunch of keys from his pocket and opened the door of his laboratory. He fumbled for his matches and lit the gas. His X-ray apparatus was all set up for an experiment. Professor Becquerel sat down at his desk and began to study the results in his notebook.

"*Tiens!*" he muttered to himself. "These X-rays are strange."

He sat thinking for several minutes. At last he jumped up, went over to a set of drawers at the other end of the laboratory and began to look for something. He had decided to perform an experiment for which he would need photographic plates and now he was searching for some which he had hidden away carefully in one of the drawers. He was always careful to hide his photographic plates because the laboratory assistants were too fond of playing with them.

"*Très bien!*" he said, as he found the packet of plates in a drawer. They were wrapped, as he had left them, in thick, black paper in order to keep out the light.

Professor Becquerel placed a photographic plate, still wrapped in the black paper, in position in his apparatus, for he intended to focus a narrow beam of X-rays upon it. There was no need for him to remove the black paper and work in the dark as in other experiments using photographic plates because these remarkable rays would pass through the paper quite easily. Expertly, he made his final adjustments to the apparatus; then he switched on the X-ray beam.

At length, he switched off the beam and carefully removed the photographic plate from its holder. Becquerel put a red shade[1] around the globe of the gas-light before removing the black paper from the plate and then, working quickly and deftly, he began the process of developing the photograph. He worked methodically, with precise movements, applying the chemical solutions and lastly washing the plate with water. Finally he removed the red shade which he had placed over the gas-light and held up the photograph to the light to examine it.

"*Formidable!*" he cried out in dismay and disappointment. "*C'est impossible!*"

Instead of showing the neat track made by a narrow beam of X-rays, the photographic plate was completely fogged.

Professor Becquerel sat in his chair and contemplated the facts. The photographic plate was fogged, yet it had been carefully wrapped and kept in a drawer. What else was in the drawer? He got up, opened the drawer and examined the contents; there were some samples of a mineral called pitchblende which he had been keeping for another experiment. Could this be the cause of the fogging of the plate? Becquerel was determined to find out. He obtained a new photographic plate and placed over it some of the pieces of rock which had been in the drawer. As he had suspected, when the plate was developed, the photograph was badly fogged.

---

[1] Red light will not affect a photographic plate.

"*C'est très interessant!*" he exclaimed with satisfaction, jumping up from his chair. He now knew for certain that he was on the verge of a great discovery. Evidently, those pieces of stone were giving off some invisible rays[1] which would pass right through paper to affect a photographic plate. What sort of rays could they be? Were they harmful? Could they penetrate other substances besides paper? Where did they come from?

During the next few weeks, Professor Becquerel tried to find the answers to some of these questions. His first project was to find out how many different substances had a similar effect. He obtained as many different mineral substances as he could and tried their effect on photographic plates. The result of this work led him to think that only minerals containing the element *uranium* gave out the rays. It also seemed to him that the more uranium there was in a piece of rock the more fogged the photographic plate would become. These substances capable of giving out invisible rays are now described by a special name: they are called *radioactive substances.*[2]

---

[1] These invisible rays were at first called *Becquerel rays*, but later the term *radioactive rays* or *radiation* was introduced.

[2] The term *radioactive* was first used by Marya Curie in 1898.

THE GIRL FROM POLAND

Professor Becquerel put down his notebook and looked out of his laboratory window with great interest.

"What will that young woman from Poland be doing next?" he asked himself. "What is the University coming to?"

Professor Becquerel liked the young Curies; Pierre had been one of his best students and Marya, his Polish wife, was a fine scientist too, but to order a whole wagon-load of pitchblende was, to say the least, very extraordinary.

A horse-drawn wagon had arrived with a load of pitchblende in sacks. Apparently, Marya had managed to get this load of ore from Austria.

"She is determined, this Marya," he said to himself.

He opened the window to see what would happen next. They were carrying the sacks round to an old shed near to Marya Curie's laboratory. He could not help admiring the resolute young woman who had come out to direct operations.

He recalled the day that she had arrived from Poland, and how she lived in a poor attic and had scarcely enough to eat. There were days when all she could afford would be a bag of cherries or a piece of bread. Still, she did brilliantly in her examinations and had carried out a systematic investigation of "Becquerel radiation" to see if substances other than uranium showed similar properties: this work had been the subject of the dissertation for her doctor's degree. Now she was married to Pierre Curie, a splendid young fellow, already famous as a scientist.

Professor Becquerel could see Marya Curie helping to stack the bags of ore near the shed. She and her husband were pouring out some of the pitchblende and were inspecting it—just a dull brown powder. He knew that Marya

was convinced from her experiments that this dull material contained a wonderful radioactive substance and that she was determined to obtain some of it. The ore would have to be treated with large quantities of acids and other chemicals and then heated in a home-made furnace. It would be heavy work for a young woman, but doubtless Pierre would take time off from his other work to help her. But since that ton of ore would have to be processed and reprocessed until only a fraction of it remained, perhaps only a tiny particle of the radioactive substance, it was going to be a long and gruelling job.

The Professor closed the window.

"Better leave them alone," he said to himself. "I hope that young woman doesn't kill herself with work. It will be bitterly cold out in that shed in the winter and the place is poorly ventilated; the chemical fumes will be a danger. Anyhow, there's no stopping her once she has made up her mind."

He sank back into his chair deep in thought, wondering what would be the result of it all.

But even Professor Becquerel could hardly have guessed what the future would bring to Marya Curie. With her husband, she toiled for four years, shivering with cold in the winter and sweltering in the summer. And then, after they were almost in despair, the ton of pitchblende finally yielded a tiny piece of a new element.

How could anyone have guessed what radium would be like? It glowed in the twilight, giving off enough light to read by. It gave out enough heat in an hour to melt its own weight in ice. Even Marya and Pierre were astonished by the wonderful new element. They found that it was two million times as radioactive as uranium and that it affected everything that came near it. They soon found that the rays emitted by radium were dangerous, causing the skin to become very red and sore. A way to prevent this was to keep radium in a lead case.

Pierre Curie and other scientists made a systematic study of the effects of radium on the skin. As the experiments were too dangerous to try on other people, Pierre tried the effect on his own arm. Eventually, it was discovered that the radioactive rays given out by radium could help in the cure of skin diseases and in the treatment of the very terrible disease called cancer.

And if Henri Becquerel had been able to see into the future, he would have seen that his work and that of Marya and Pierre Curie was just the beginning: the beginning of the Atomic Age!

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CHAPTER III

SPLITTING THE ATOM

CHRISTMAS 1938 was over. The streets of Copenhagen were gay and glittering. The pavements were crowded with people, some rushing home from work to New Year's parties and others going excitedly in search of their evening's entertainment. The cafés and restaurants were full and the Tivoli pleasure gardens were already lit up with myriads of coloured lights and illuminated fountains.

From the window of his laboratory, Otto Frisch watched the happy faces of the people in the street below and tried to guess their thoughts as they called "Happy New Year!" to their friends. He knew from scraps of conversation overheard on buses and at street corners that deep down everybody was afraid. Tonight people were making a desperate attempt to be gay and to forget the newspaper headlines which gave an awful warning of what the new year could bring.

No one knew better than Otto Frisch what those headlines meant. He had seen Hitler rise to power; he had watched the growth of Germany's military might and he had felt the hatred and suspicion which came as a consequence. How could a scientist, dedicated to finding out the truth, live and work in a land of secret police, political spies and ruthless persecution of innocent people? He and his aunt, Dr. Lise Meitner, who was herself a great scientist, had escaped from Nazi Germany before it was too late. How long would it be before Hitler's troops would try to over-run the whole of Europe?

Otto Frisch had come to Copenhagen to work with the

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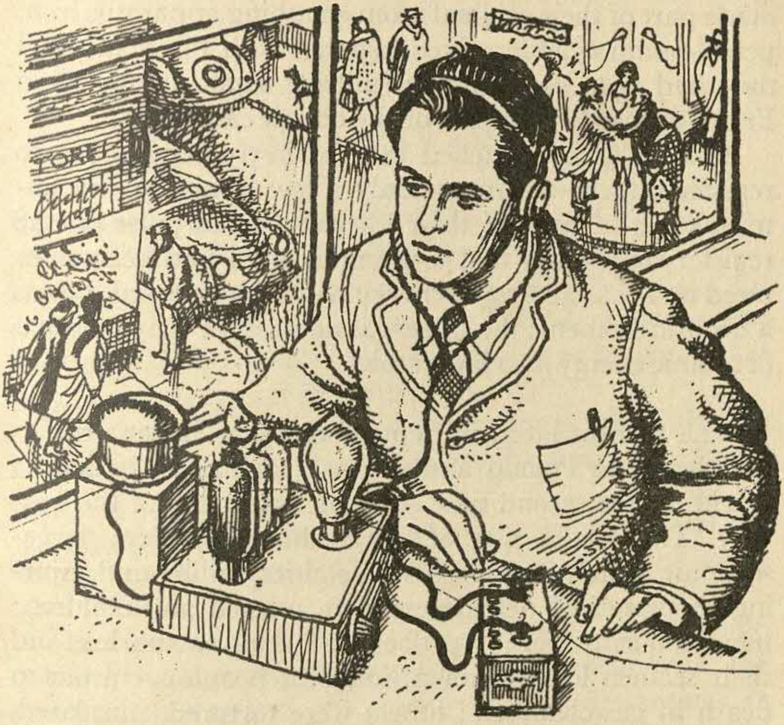
famous Danish scientist, Niels Bohr; Lise Meitner had gone to peaceful Sweden. Herr Frisch was thankful that his aunt was safe in Sweden, for it was unlikely that Hitler would interfere with this neutral country. When he visited her at Christmas he was glad to see that she had been made welcome and that she could continue her research work.

It was like old times being with Aunt Lise: they enjoyed being together and exchanging their ideas on scientific problems. As usual, she had given him something to think about: a letter from her old friend and collaborator, Professor Otto Hahn in Berlin. This letter contained an idea so exciting that he could scarcely believe it! At first, he would not listen to her—it was too fantastic. Even now it seemed unbelievable. How could the impact of a tiny atomic particle smash a uranium atom into bits? It was true that bits had been chipped off atoms by shooting minute atomic particles into them. Two English scientists, J. D. Cockcroft and E. T. S. Walton, had actually succeeded in splitting some very small atoms more or less in two. But to shatter a uranium atom—the largest atom of all—why, one might as well try shooting peas at an elephant!

Yet he knew that Hahn was too good a scientist to put forward an idea like that unless there was some very convincing evidence for it. He had mentioned Hahn's idea to Niels Bohr, just before the professor had left for a visit to the United States. Niels Bohr had been very impressed by it and had promised to discuss the idea further with atomic scientists in America. This had been reassuring; yet it still seemed incredible.

The problem was this: the parts of an atom are held together by strong forces. These would have to be broken before the atom could be smashed. Surely, then, a great deal of energy would be released if this happened! Otto Frisch had decided not to wait until Niels Bohr had re-



turned from the United States before putting these conjectures to the test.

He turned round and looked at the apparatus which he had collected together. It was simple enough: an ionisation chamber made from two metal plates joined by a ring of glass, which was connected to an electric circuit in which an instrument would show if there were any bursts of energy within the chamber. One of the metal plates carried a layer of uranium, which was to be the target of a stream of tiny atomic particles. Now the moment had arrived, the apparatus seemed altogether too crude to carry out such an experiment. Still, Cockcroft and Walton had made part of their original atom-smashing apparatus from petrol-pump cylinders fixed together with Plasticine, and they had been successful in splitting small atoms! Otto Frisch checked every part of the circuit carefully.

As soon as he switched on, the instrument began to register pulses—not many, only a few a minute, but unmistakable because of their intensity. Each pulse on the register set showed that a uranium atom had been shattered and that a burst of energy had been released. It was a historic moment; the stage was now set for the liberation of atomic energy on a large scale.

Nine months later, in September 1939, Hitler's troops marched into Poland and war was unleashed upon the world for the second time since the beginning of the century. This was a war of extraordinary cruelty: large-scale air attacks destroyed whole cities, killing and injuring thousands of defenceless men, women and children; merchant ships were torpedoed by lurking submarines and their seamen left to drown; innocent people were put to death in gas-chambers; others were tortured, mutilated, or made the subjects of terrible "scientific" experiments.

The war raged for six years, involving nearly all parts of the world, and it might have lasted much longer but for the use of the terrible new weapon, the atomic bomb. A single atomic bomb virtually destroyed Hiroshima, another destroyed Nagasaki, and if atomic warfare becomes unleashed again, it is quite possible that every great city in the world will be obliterated.

The revolutionary idea of Otto Hahn and the simple experiment of Otto Frisch had been used with devastating effect.

CHAPTER IV

UNDER POLAR ICE

COMMANDER William R. Anderson, captain of the nuclear-powered submarine U.S.S. *Nautilus*, glanced at his watch. It was a few minutes past midnight and a new day, 3rd August, 1958, was just beginning. The Commander was not the only one unable to sleep; every man on board was up and about, agog with excitement.

Men not on duty relaxed in the mess, the juke-box blaring incessantly as they sat in groups, swapping stories, laughing and talking.

"Boy, this is the way to explore," exclaimed one of the crewmen who was seated smoking a pipe, a cup of coffee beside him.

The Commander smiled at this remark, for he could not help comparing the comfort of *Nautilus* with the cramped quarters of the diesel-powered submarines in which he had served. Here they were, cruising at twenty knots below the treacherous ice of the Arctic Ocean, yet the ship was warm and air-conditioned, there were good hot meals, a well-appointed mess where snacks and light refreshments could be obtained, a library and frequent film shows. Even the walls were painted in pleasing colours to give a sense of spaciousness.

As he had often told his men, *Nautilus* was the first true "submarine", as it was designed for underwater operations and nothing else. Older submarines with oxygen-breathing diesel engines *had* to spend much of their time on the surface.

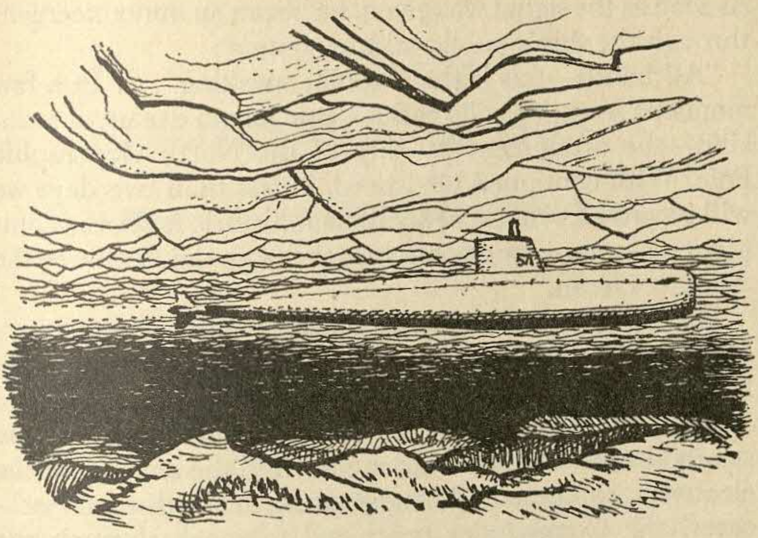
The Commander continued his rounds, examining an instrument here, studying a chart there, stopping to have a word with members of the crew at their duty stations. He was pleased to see that every man was in his place and that all was in good order.

Commander Anderson was very proud of his men. Although many of them were young, they had all been carefully chosen for their special work. Every member of the crew regarded himself as a member of a team that must function efficiently and smoothly. They had been chosen for their steady, unselfish personalities that could be expected to withstand the confined and rather cramped conditions of submarine life without outbursts of temper or moodiness. These men would have to be relied upon in an emergency and a selfish or unintelligent action on the part of one man could mean death to his mates.

In spite of the general excitement, everyone knew that this was no time to be over-confident. A fault in any part of the equipment could mean that they would have to turn back or perhaps become stranded beneath the ice.

Everything was checked and rechecked. Dr. Waldo Lyons, a scientist and one of four civilian members of the crew, remained hour after hour operating the ice-detection apparatus as it plotted the position of the thick, jagged ice overhead. The ice was as hard as rock, so collision with it could be fatal. No less important were the readings of the fathometer which traced the shape of the floor of the ocean. The sea bottom was anything but flat; there were underwater mountains and valleys, sheer cliffs and peaks which stuck up like spikes. More than once, as the water suddenly became shallower, the Commander had given orders for speed to be slackened.

Now things were going well and the nuclear-powered engines purred contentedly as the submarine sped northwards.



As the hours passed, the men on duty watch were thrilled and delighted by the rapid progress. The electronic machines clocked mile after mile, and with each mile, *Nautilus* was making naval history. Tension mounted with the realisation that it could be only a matter of minutes before *Nautilus* would reach her objective—the North Pole. The sonar equipment[1] indicated that the pack ice above was running between eight and eighty feet thick, and it was easy to imagine the barren wastes of cruel ice and howling wind in the uncharted territory above.

A mile south of the Pole, the Commander ordered the navigator to inform him when they were four-tenths of a mile from the Pole as indicated by the electronic log. He knew that the crew had gathered in the attack centre and the crew's mess and that they were waiting expectantly.

---

[1] Sonar equipment is used in submarines to measure distances from the ocean bottom or from overhead ice. The measurement is based on the time interval between sending out a sound and receiving its echo as it is reflected from an obstacle.

As soon as the signal was given, he began an announcement through the ship's public-address system:

"All hands—this is the Captain speaking. . . . In a few moments *Nautilus* will realise a goal long a dream of mankind—the attainment by ship of the North Geographic Pole. With continued Godspeed, in less than two days we will record an even more significant historic first: the completion of a rapid transpolar voyage from the Pacific to the Atlantic Ocean."

He then asked the crew to pause in silence, remembering those who had attempted to reach the North Pole before them and to offer a prayer for lasting world peace.

A hush fell over the ship. The only sounds were the steady drone of the nuclear engines and the clicking of the electronic equipment. Then, glancing at the distance indicator, the Commander continued to speak through the microphone:

"Stand by. 10 . . . 8 . . . 6 . . . 4 . . . 2. . . . 1. MARK!"

There was a mighty cheer from the crew's mess.

On 5th August, after ninety-six hours under the ice, *Nautilus* surfaced north-east of Greenland; a day later the crew saw their first land since leaving Alaska—the island called Jan Mayen, which is north of Iceland. Another six days and *Nautilus* had crossed the north Atlantic Ocean and was heading full speed for England. On Tuesday, 12th August, she steamed into Portland, England, and received a tumultuous welcome. After spending six days in England, *Nautilus* broke the speed record for a submerged crossing to New York, where the crew were greeted and honoured in typical American style. The epic voyage was completed and *Nautilus*'s nuclear engines had propelled her more than 129,000 miles without refuelling—a triumph of seamanship and nuclear engineering.

PART II

REFERENCE SECTION

HOW TO FIND OUT MORE ABOUT ATOMS

In this section you can find out more about atoms, how very small they must be, how men have tried to find out what atoms are like, and how when atoms have been split energy is released. Here, in addition to a description of how atomic energy has been used as a weapon of war, you will find a discussion of many of its peaceful applications: nuclear power stations, nuclear-propelled submarines and ships, and the use of radioisotopes in scientific research, in fighting disease, in industrial and many other processes. This section tells how, if used wisely, the unlimited supply of energy of atoms could help to alleviate hunger and want everywhere and enable all people in the world to lead fuller and happier lives.

1. HOW THE UNIVERSE IS MADE UP

ALL the things which make up the universe—rocks, water, trees, air, television sets, human beings—are made up of about one hundred different kinds of substances. These different sorts of matter are called *elements*.[1] New elements may be discovered in the future, but scientists believe that the total number of elements is about one hundred. Here are some of the elements which go to make up a television set.

iron

aluminium

carbon

hydrogen

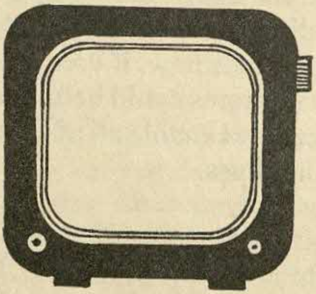
oxygen

silicon

tungsten

copper

and others



A television set is a complicated apparatus and therefore it is not surprising to find that it contains quite a number of different elements.

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[1] See Table of Elements, pp. 112 and 113.

The human body is a much more remarkable and complicated machine than a television set and scientists have found out that a very large number of elements make up a human being:

- carbon
- hydrogen
- oxygen
- nitrogen
- sulphur
- phosphorus
- calcium
- iron
- chlorine
- magnesium and many others

Water, on the other hand, is a very simple substance made up of just two elements: hydrogen and oxygen. Scientists write H_2O for water because it is made up of two parts of hydrogen for every one part of oxygen.[1] All compounds can be written in a shorthand form like this because each element has a special symbol. It is quite easy to guess some of the symbols, like H for hydrogen, O for oxygen, P for phosphorus, Ca for calcium, Si for silicon, Zn for zinc; but others, like Fe for iron, K for potassium, Pb for lead, are not so obvious. Before looking at the table of the elements and their symbols on pages 112 and 113, try to guess which elements make up the following compounds:

---

[1] Two parts of hydrogen to one part of oxygen by volume under standard conditions of temperature and pressure (twice as many H atoms as O atoms).

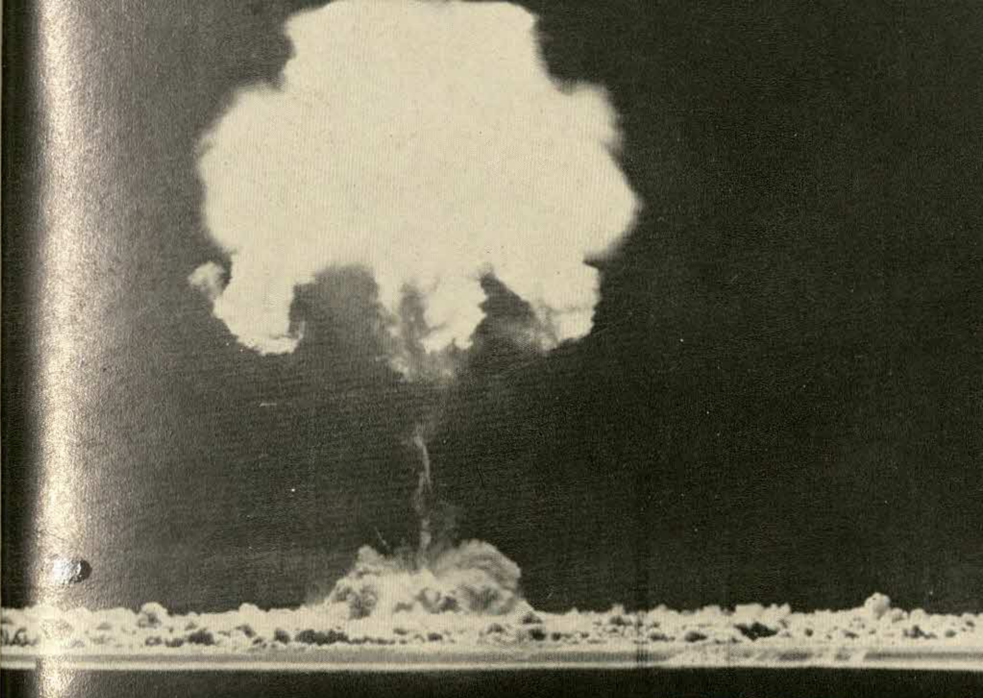
Substance	*Formula*	*Elements in the substance*
sugar	$C_6H_{12}O_6$	carbon, hydrogen, oxygen
lime	CaO	
carbon dioxide	CO_2	
acetylene	C_2H_2	
ammonia	NH_3	
soot	C	
nitric acid	HNO_3	
chalk	$CaCO_3$	
sand	SiO_2	
milk of magnesia	$Mg(OH)_2$	
lead chloride	$PbCl_2$	

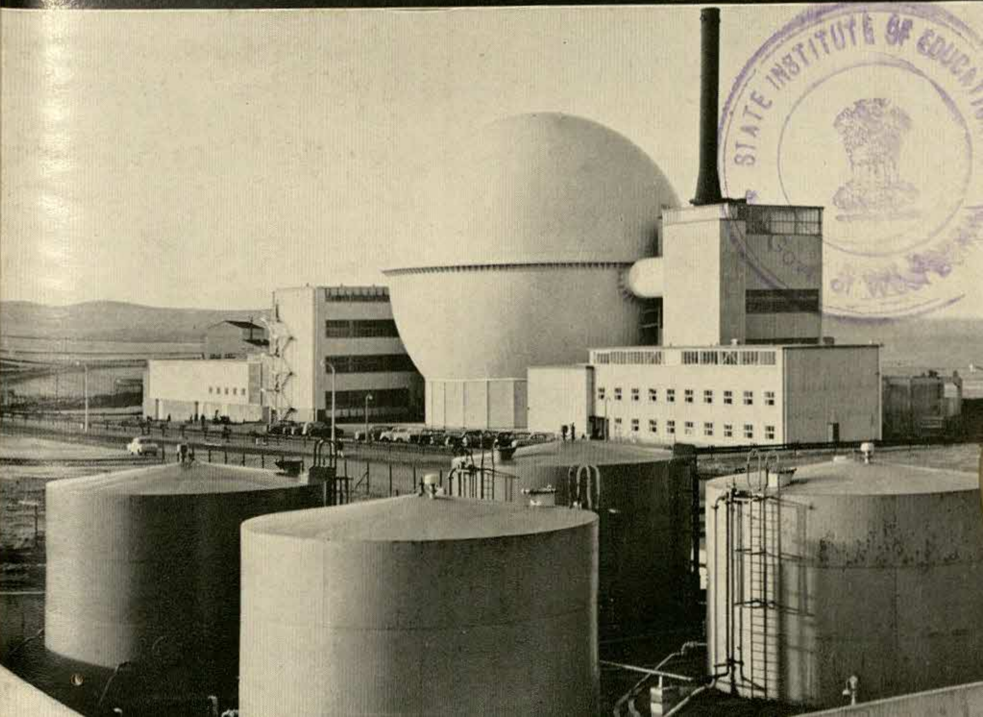
Ten correct answers, without any help from the list on pages 112 and 113, must indicate a budding scientist!

ELEMENTS ARE MADE UP OF ATOMS

The elements are made up of very small particles called *atoms*, and all the atoms of a particular element are exactly the same. A bar of iron is composed of millions of iron atoms which are all the same. Of course, atoms of iron are different from atoms of another element, for example from atoms of copper or of uranium. As might be expected, an iron atom is much heavier than a hydrogen atom. On the other hand, atoms of uranium are many times heavier than atoms of iron. As a matter of fact, hydrogen atoms are the lightest atoms and uranium atoms are some of the heaviest. Scientists have been able to work out that a uranium atom is about 238 times as heavy as a hydrogen atom.

(Above)* ATOMS FOR WAR: *an atomic bomb is exploded
(Below)* ATOMS FOR PEACE: *the nuclear reactor at Dounreay





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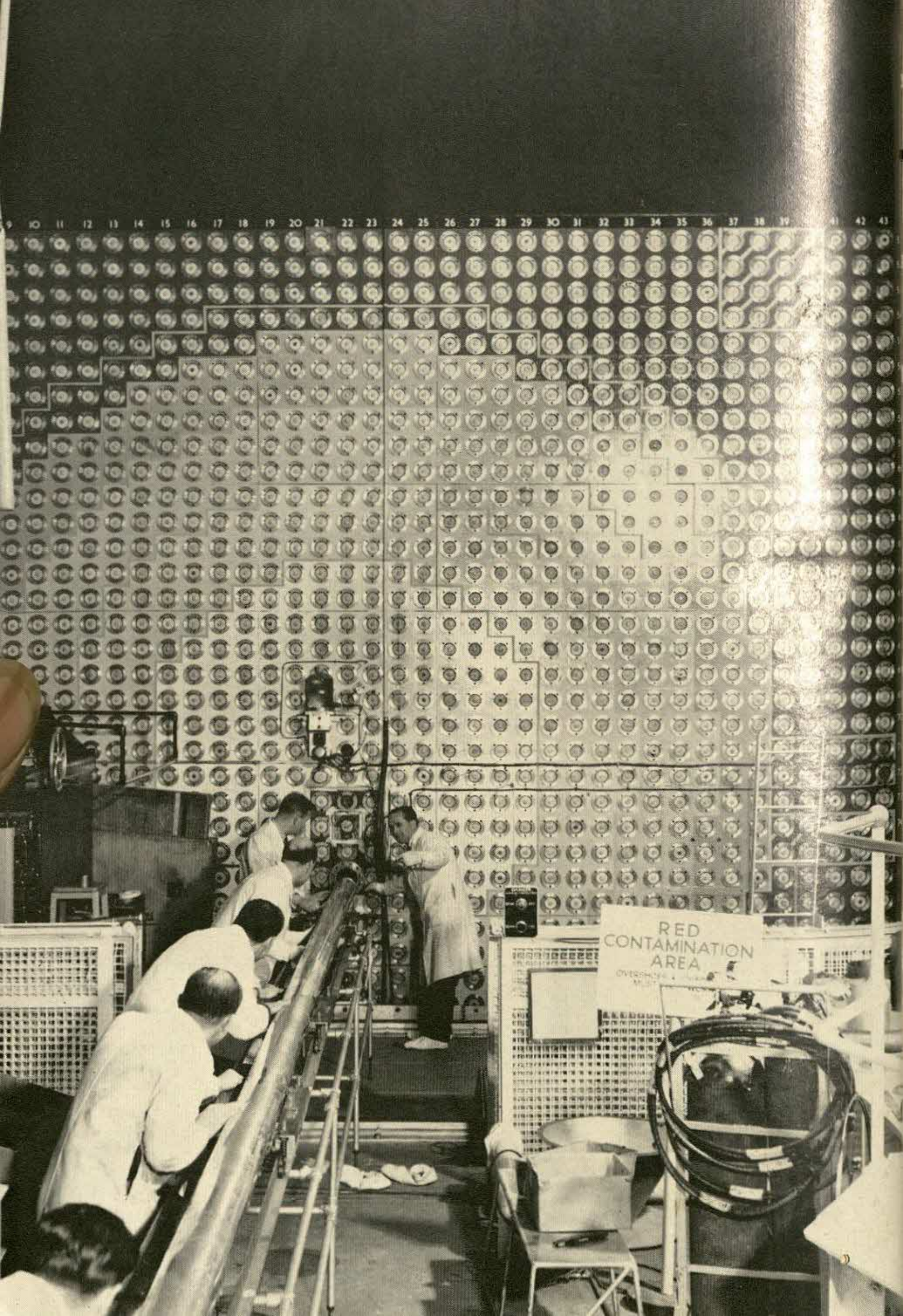
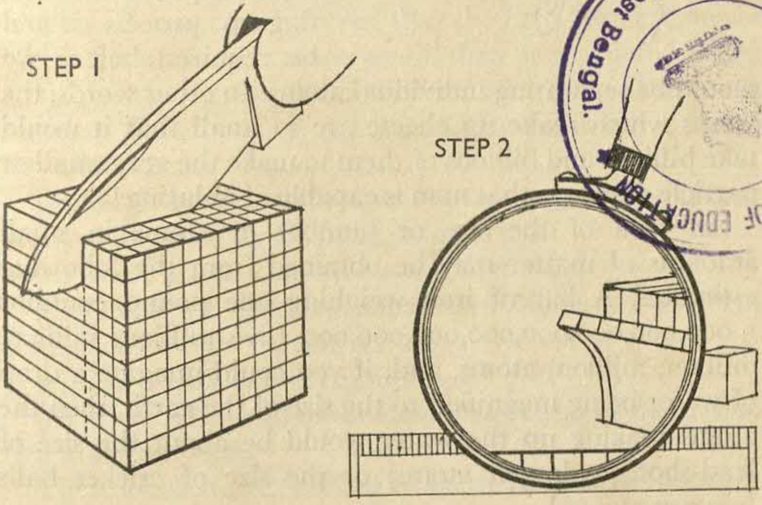

9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 41 42 43
RED
CONTAMINATION
AREA

HOW BIG IS AN ATOM?

Even uranium atoms are very, very small. It is hard to understand how very tiny atoms must be.

Imagine taking a cube of cheese measuring an inch each way. Cheese is made up mainly of atoms of carbon, hydrogen, oxygen and nitrogen. If the cube of cheese were carefully sliced with a sharp knife into cubes one-tenth of an inch each way, one thousand cubes would be produced. If the process were repeated with one of these small cubes—perhaps by using a razor-blade and with the help of a magnifying glass—pieces one-millionth of the size of the first cube would be obtained. Although you might find it difficult to believe, it is possible to repeat this cutting-up process twice more by looking at each tiny fragment through a microscope and by using what are called micromanipulators to handle it. The result would be exceedingly small cubes one *million-millionth* of the size of the first



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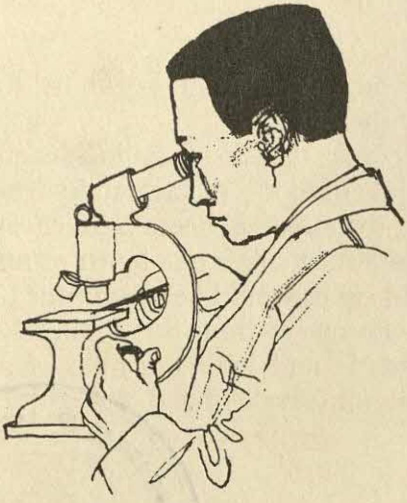
BEPO (*British Experimental Pile Zero Energy*) *at Harwell*



piece of cheese. It would be found impossible to divide up the cheese any further, even with the most powerful microscope in the world and the very latest and best micro-manipulators. Even so, such a chopping-up operation would get only half-way to the atom and four more steps in the cutting-up process would be required before we should be separating individual atoms. In other words, the atoms which make up cheese are so small that it would take billions and billions of them to make the very smallest particle of cheese that man is capable of isolating!

An idea of the size or number of atoms in small amounts of matter may be obtained from the following estimates. A bar of iron weighing one pound contains 5,000,000,000,000,000,000,000,000 (five million, million, million, million) atoms, and, if you could imagine a drop of water being magnified to the size of the earth, then the atoms making up the water would be about the size of lead-shot (hydrogen atoms) or the size of cricket balls (oxygen atoms)!

How then have scientists found out anything about atoms if they are far too small to be seen through the most powerful microscopes? It is said that "seeing is believing"; well, nobody has ever seen an atom!

II. EARLY IDEAS ABOUT ATOMS

ONE of the best answers to the question of how the universe is made was put forward by Democritus, a Greek who lived several hundred years before the birth of Jesus Christ. He came to the conclusion that if a piece of anything was divided up into smaller pieces and each of these pieces subdivided into still smaller pieces, then a time would come when it would not be possible for the piece to be broken any further. Democritus believed that the final "bricks" out of which the universe is made would then be reached. He was only making a guess, for he had no scientific evidence for his idea. These "bricks" which make up the whole universe he called *atoms*.[1]

Democritus tried to imagine what the atoms would be like and he made the following suggestions:

(*a*) They are solid and the same all through.

(*b*) Atoms of different substances might be different from each other in size and shape.

(*c*) They are always in motion.

(*d*) There is no end to the number of them as there is no end to the universe.

These ideas are astounding when we remember that they were put forward such a long time ago.

THE ALCHEMISTS

During the Middle Ages, there were some people who were interested in carrying out chemical experiments, especially with metals. They were the *alchemists,* who dreamed of becoming rich quickly. There are several old pictures and drawings of alchemists at work which give a very good idea of their methods and of the apparatus they used.

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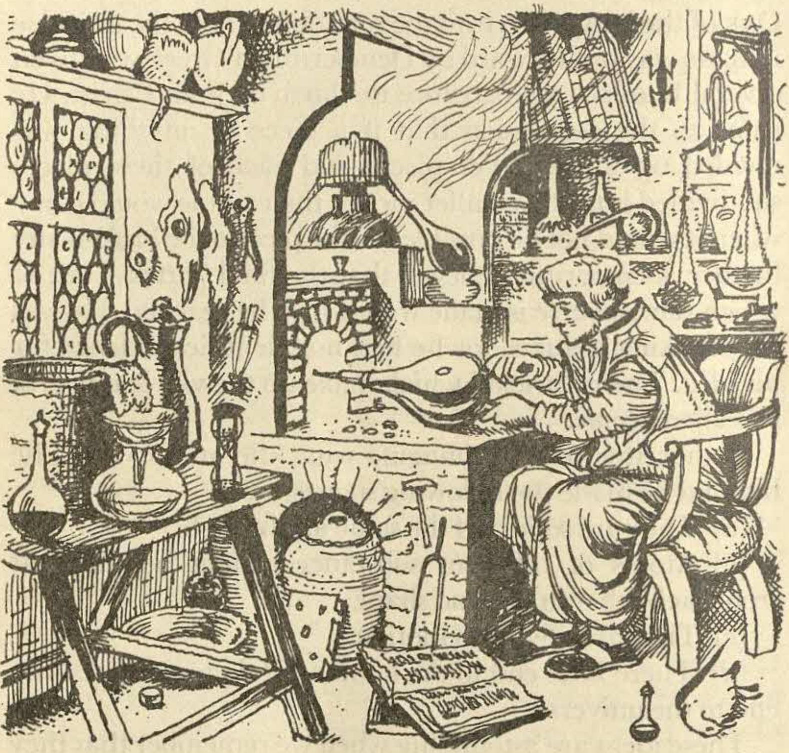
[1] From Greek *a*, not; *temno*, I cut: that is, something which cannot be cut.



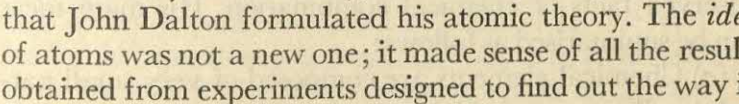
Look at this picture of an alchemist working in his laboratory. There is a furnace for heating metals, and the tables and benches are covered with basins, bottles and jars of all kinds. Notice other pieces of apparatus which appear in the picture: retorts with long necks, bellows for blowing the fire, an hour-glass for telling the time. Notice also the large books which may be supposed to contain vital information about the mysterious art.

In spite of the superstitious nature of many of the beliefs of the alchemists, their work was of great value in showing how to perform experiments. They learned the importance of careful observation and of writing down the results of their experiments. Alchemists never succeeded in *transmuting* lead into gold and it is very unlikely that this change will ever be achieved, but twentieth-century scientists have shown that the *transmutation* of one chemical element to another is not an idle dream.

JOHN DALTON AND THE ATOMIC THEORY

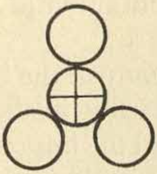
The years between 1803 and 1808 were very important in the history of chemistry, for it was during this period that John Dalton formulated his atomic theory. The *idea* of atoms was not a new one; it made sense of all the results obtained from experiments designed to find out the way in which elements combine together to form compounds. The atomic theory led to chemical symbols being given to each element and chemists were soon writing down formulae for chemical compounds. John Dalton invented his own system of formulae, but it was rather cumbersome and not so easy to use as the modern system.

Dalton's Symbols

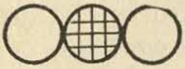


Compounds

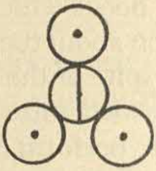
Using Dalton's symbols, compounds could be represented thus:



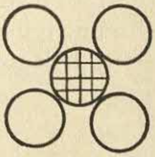
ammonia, NH_3



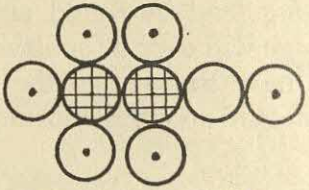
carbon dioxide, CO_2



sulphur trioxide, SO_3



methane, CH_4



ethyl alcohol, C_2H_6O

Dalton's atomic theory was successful in explaining the observed facts of chemical combination. His main ideas can be summarised as follows:

(*a*) Chemical elements are composed of very small particles called atoms which are not split up in any way in chemical changes.

(*b*) There is a definite weight for every kind of atom. Different elements have atoms differing in weight.

(*c*) Chemical combination takes place by the joining together of atoms of different elements.

We call the compound particles formed by the union of atoms *molecules*. Thus, a molecule of carbon dioxide is made up of one carbon atom and two oxygen atoms, and a molecule of ethyl alcohol, which is a constituent of wines and spirits, is composed of two carbon atoms, six hydrogen atoms and one oxygen atom.

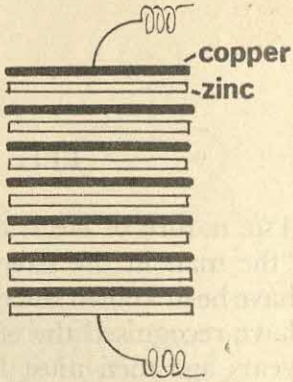
The year 1808, when Dalton's Atomic Theory was published, can be claimed as marking the beginning of modern chemistry—or even the beginning of the Atomic Age.

III. ELECTRONS

THE nature of electricity has puzzled scientists as well as "the man in the street", even though some of its effects have been known since earliest times. Prehistoric man must have recognised the effects of lightning, and thousands of years ago men must have been fascinated by the "static electricity" produced when certain things are rubbed together. Everybody knows that a comb which has been rubbed briskly with a piece of cloth will pick up bits of paper in the same way that a magnet picks up iron filings.

Benjamin Franklin, an American, was one of the first men to try experiments with electricity. In one very remarkable experiment he was lucky not to have killed himself! He flew a kite in a thunderstorm in an attempt to catch some electricity from a thunder-cloud. He succeeded, for the electricity travelled along the wet string and he received a severe electric shock. It is not advisable to try to repeat this famous experiment because the shock could easily be violent enough to kill a person. Benjamin Franklin carried out this "kite" experiment in 1752—more than two hundred years ago.

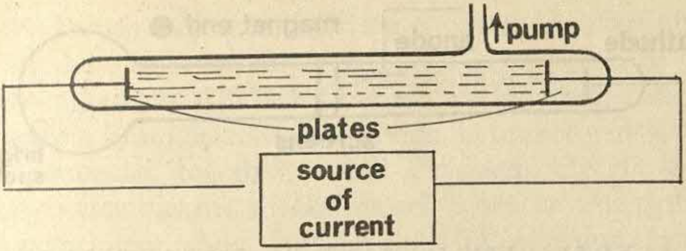
About the same time, Alessandro Volta, an Italian, invented the first electric battery and so provided the first source of a continuous current of electricity. Volta's battery was nothing more than a pile of metallic discs, copper and zinc alternating, with strips of cloth soaked in salt water providing the contact between them. Although Volta had found out that two different metals placed together in this way could give an electric shock if both metals were touched at the same time, he had no idea how this happened. It was a long time before enough facts were collected about electrical phenomena to give scientists an insight into the nature of electricity and for them to understand how batteries work.



The next 150 years saw a great advance in man's experience with electricity. Perhaps the greatest achievement was the realisation that static electricity, electricity produced by batteries and lightning are all the same. By the end of Queen Victoria's long reign, electricity could be described, it could be generated by dynamos and it could be accurately measured. But nobody knew the answer to the question, "What *is* electricity?" Of course, scientists and others argued about it: some thought that electricity must be some kind of invisible liquid.

But in 1897, J. J. Thomson, an English scientist working at Cambridge University, devised some very interesting experiments which, in the end, provided the answer to the question which had baffled men for so long.

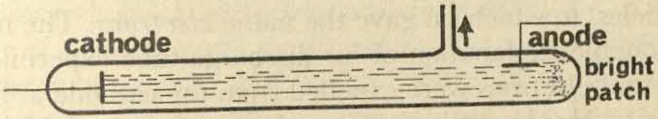
He got a strong glass tube and sealed wires through the ends. A metal plate was fastened to each wire and then the whole thing was connected up to a source of electricity. When the current was switched on, nothing happened! The air in the tube provided too much resistance for the electricity to jump from one plate to the other. So the air was pumped out with a suction pump, similar to the pump in a vacuum cleaner, and the experiment was tried again. This time the electricity was able to jump across the gap. It was evident that it must be *something* if it was able to



jump from one plate to another!

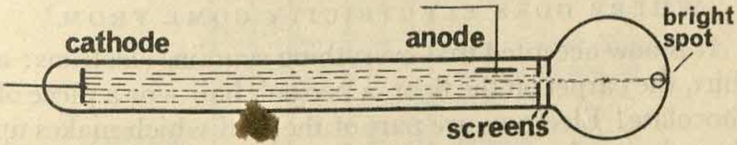
The metallic plate from which the electricity came was called the *cathode*[1] and the other plate was called the *anode*.[2]

It was soon discovered that if the anode was moved a little to one side, a straight beam of rays from the cathode would shoot right past it and a bright patch would appear



on the glass at the end of the tube. Professor Thomson found that he could narrow down the beam into a thin pencil of rays by fixing little screens with slits in them inside the tube in the path of the rays.

Next, he tried the effect of a magnetic field on the cathode rays and found they were deflected. The stronger the magnet, the greater was the deflection of the rays.



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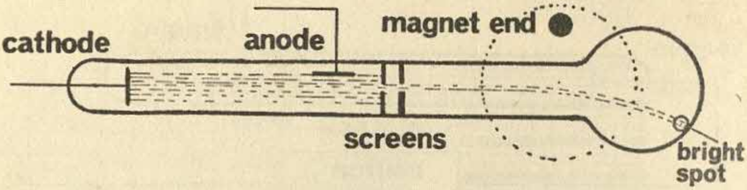
[1] From Greek *kathodos,* meaning descent or going down.
[2] From Greek *anodos,* meaning ascent or going up.



ELECTRICITY IS MADE UP OF PARTICLES

If a glass plate is coated with zinc sulphide and then placed in the path of some cathode rays, it will light up. The glow is made up of hundreds of tiny bursts of light all over the surface, as though separate hits are being made by individual particles. This seems to suggest that electricity is, in fact, made up of a stream of tiny particles. However, this evidence was unknown to J. J. Thomson who first came to the conclusion that electricity is a stream of charged particles, to which he gave the name *electrons*. The most reasonable explanation of his discharge tube experiments was that electrons were expelled from the cathode at high velocity. He also devised an ingenious experiment which enabled him to calculate the charge of an electron compared to its mass.

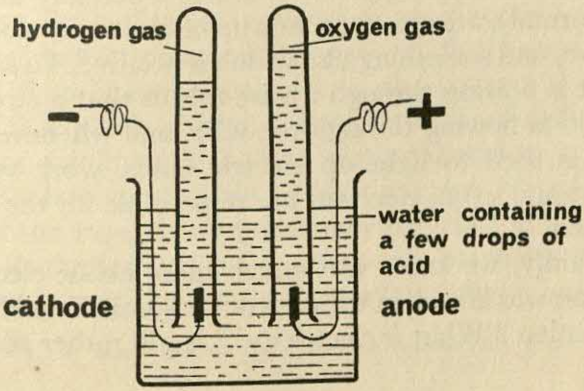
After years of careful research in many parts of the world, scientists have found out many things about these particles, such as their weight, the speed at which they travel and how they behave in an electric circuit.

WHERE DOES ELECTRICITY COME FROM?

It is now accepted that everything contains electrons: a shirt, the carpet on the floor, a person's hair—or a piece of chocolate! Electrons are part of the stuff which makes up the universe. It seems that electrons can be rubbed off some materials fairly easily. Combing one's hair, for instance, is a well-known way of transferring electrons from one place to another. If electrons are collected in an insulated jar, eventually there will be enough to give an electric shock. Benjamin Franklin collected enough, in properly insulated jars connected together, to kill a chicken. He got some pretty nasty electric shocks himself when he was getting the experiment ready! Insulated jars for collecting electric charges are called Leyden Jars and your school laboratory may have some.

ELECTROLYSIS OF WATER

Not only do all kinds of matter contain electrons, but the properties of different kinds of matter depend on the number and arrangement of the electrons within them. Electrons are the "cement" which helps to bind together different chemical elements into compounds. By sharing some of their electrons, hydrogen and oxygen are held together to form water. If this "link" is broken, the hydrogen and oxygen will be set free again as gases. It is found that if more electrons are sent into water, the electronic arrangement is upset and the water breaks down into its constituent



elements. This is called the electrolysis of water and it is quite an easy experiment to set up.

Two test-tubes are filled with water and inverted in a beaker containing water. It is best to add a few drops of acid to the water. Two small strips of platinum make excellent electrodes (cathode and anode), but carbon could be used. The electrodes are connected to a source of *direct* current—say, a car battery. Bubbles of hydrogen will appear at the cathode and will collect in the tube. Oxygen will come off at the anode and will collect in its tube. It will be found that the volume of hydrogen obtained will be twice that of oxygen.

THE ANSWER TO THE QUESTION

What can we say in answer to the question, "What is electricity?" Electricity is a stream of electrons, which are small negatively-charged particles weighing 1/1837th of a hydrogen atom. Electrons are essentially components of all matter. As a rule, objects are electrically neutral and so are their atoms. If, however, some of their surface electrons are brushed off in some way, the object becomes positively charged while the substance which has acquired the electrons becomes negatively charged. Therefore atoms in their normal state must be made up of electrons, which are negative, and something else which is positive. To say that current is flowing through a wire means that a stream of electrons is flowing through the wire, and whenever electricity is used to light up electric bulbs, work vacuum cleaners and so on, electrons are responsible for the effects produced.

Certainly, we know very much more about electricity now than was known in the days of Benjamin Franklin, but the question, "What *is* electricity?" is still rather puzzling.

IV. THE NUCLEUS OF THE ATOM

It was mainly from the study of radioactivity and of electricity that a new picture of the atom was gradually forming in men's minds. All the evidence seemed to point to the fact that atoms are made up of two main parts, electrons plus something else. What was this "something else"? One way of trying to find out was to make a study of radioactive substances and the particles and energy given out by them.

RADIOACTIVITY

Pierre and Marya Curie were awarded the Nobel Prize for Physics (jointly with Becquerel) in 1903. The Curies' work was on radium and similar substances, but their research was concerned mainly with the chemical and medical aspects of radioactive substances.[1] Other scientists were beginning to ask themselves what the radioactive rays were composed of and whether the radioactive substances themselves changed in any way.

Ernest Rutherford was one of these. He made a study of the radiation given out by radium. By placing a few grains of radioactive material in the bottom of a hole drilled in a block of lead, a straight beam of radioactive rays was obtained. A circular spot produced on a photographic plate, or on a zinc-sulphide screen placed in the path of the rays, showed that they travelled in a straight beam. Rutherford tried the effect of a magnetic field on the rays. Part of the beam still went straight on and made

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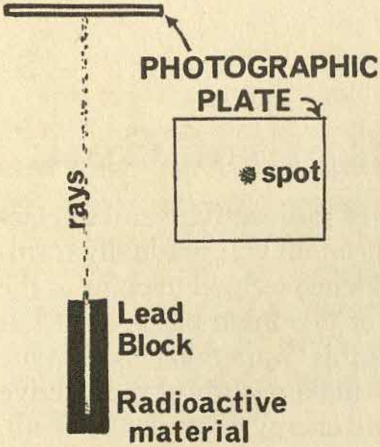
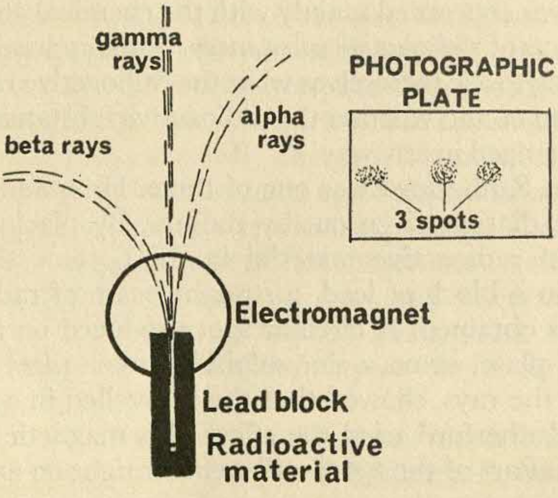
[1] The story of Marya Curie's early work on radioactivity is given on pp. 18–20.



a circular spot on a photographic plate placed directly ahead of it. However, if the plate was placed nearer to the lead container, two other spots appeared. This result made him think that radioactive radiation is made up of at least three different kinds of rays. He decided to call them alpha (α), beta (β) and gamma (γ) rays. (α, β and γ are the the first three letters of the Greek alphabet.)

Further experiments showed that the beta-rays were streams of electrons and that the gamma-rays were similar to X-rays.[2] The alpha-rays were something new!



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[2] See p. 117 for a definition of X-rays.

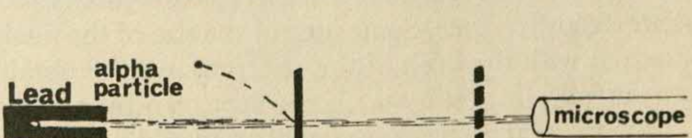
ALPHA-PARTICLES

Judging from the amount that and the direction in which the alpha-rays were bent by the magnetic field, Rutherford deduced that the rays were made up of particles which were considerably heavier than electrons and that the particles were positively charged: he called them *alpha-particles*. Eventually, Rutherford found that the alpha-particles are about four times as heavy as a hydrogen atom and carry a double positive charge.

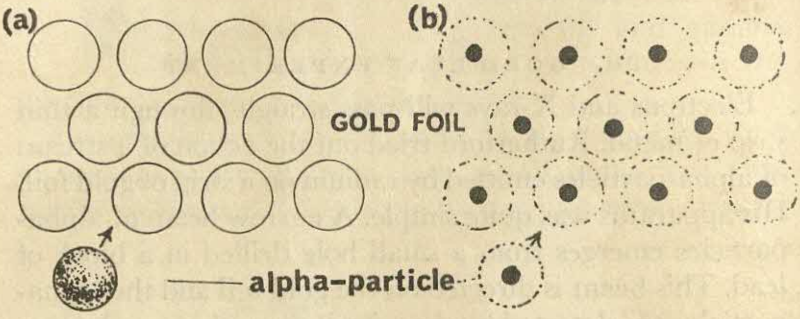
THE GOLD LEAF EXPERIMENT

Electrons and X-rays will pass straight through a thin strip of metal. Rutherford tried out the action of a stream of alpha-particles emitted by radium on a strip of gold foil. His apparatus was quite simple. A narrow beam of alpha-particles emerges from a small hole drilled in a block of lead. This beam is directed on the gold foil and the alpha-particles are detected by the scintillations they produce on striking a fluorescent screen. The scintillations are observed through a microscope placed behind the screen. The screen and microscope together are fixed on to an arm so that they can be moved to different positions along a circle. Thus alpha-particles leaving the foil in any direction may be observed and scintillations give a measure of the number shooting out in each direction.

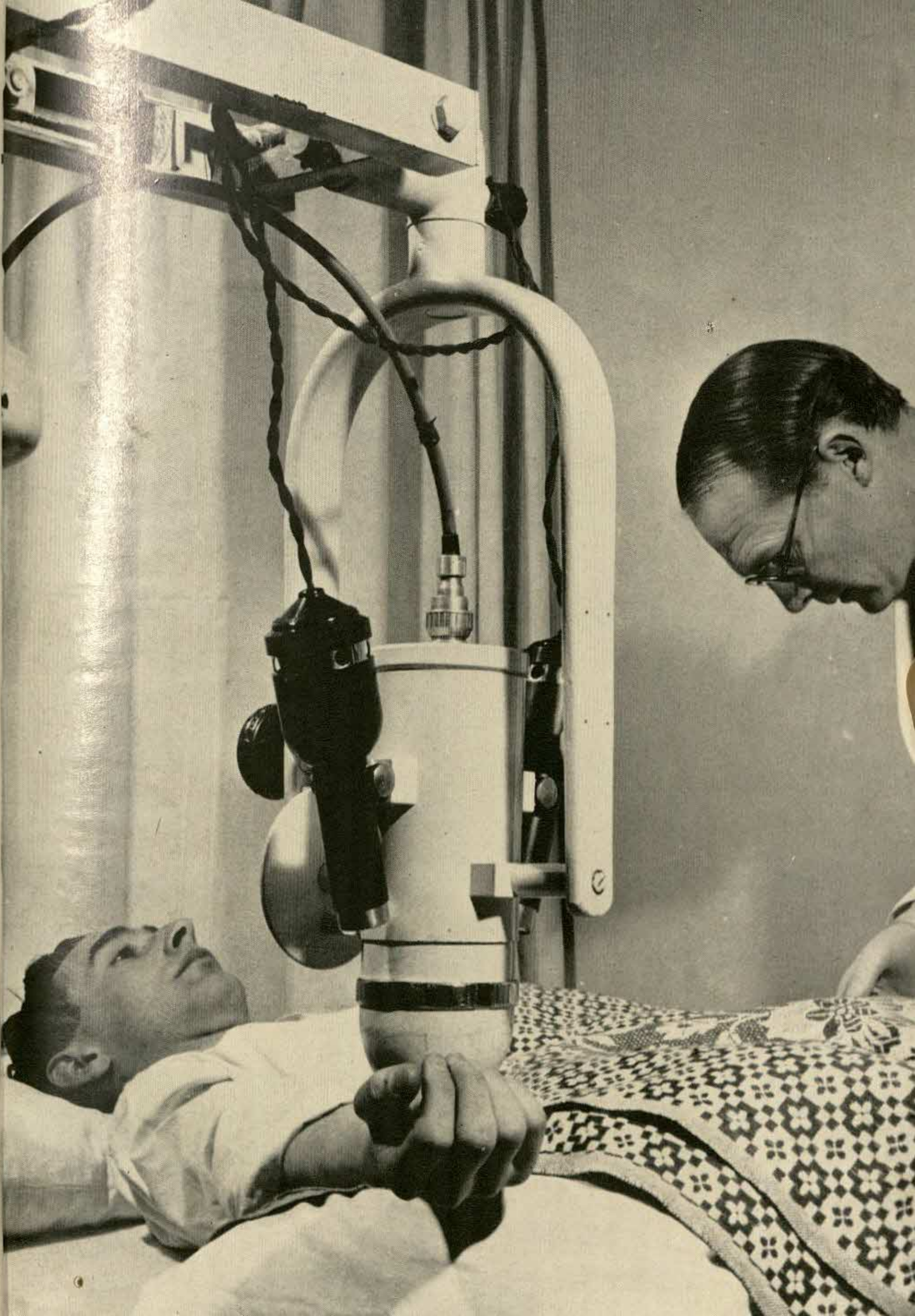
Rutherford discovered that the vast majority of the par-



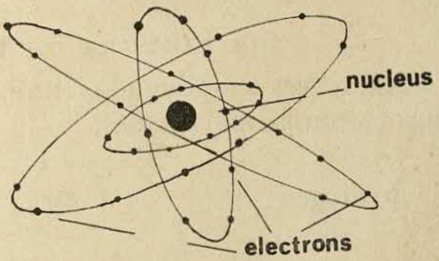
ticles went straight through the gold foil or were very slightly deflected, but an occasional particle made a head-on collision and rebounded back. If the gold atoms making up the strip of gold foil were round and hard as Dalton had imagined (diagram *a*), many more alpha-particles would have rebounded. It seemed instead that most of an atom is made up of empty space. How could this be? After careful consideration of all the facts, Rutherford came to the conclusion that an atom is like a solar system, so the atoms composing a strip of gold foil could be represented as in diagram *b*. This picture of the atom not only "explains" how most alpha-particles pass through the gold foil in Rutherford's experiment, but also how it happens that some of them rebound. After turning over all the facts in his mind, he concluded that an atom is composed of a small, heavy, positively-charged nucleus with electrons spinning around it. An atom is mostly space—just as a solar system is mostly space. Some idea of the size of the nucleus compared with the orbit of the electrons may be obtained from the following estimate: if the electron orbit ran round a 440-yard running track, the nucleus would be about the size of a pea at the centre. No wonder that few alpha-



A MEDICAL EXPERIMENT USING RADIOISOTOPES



particles in Rutherford's experiment scored a head-on collision with the nuclei of the gold atoms in the strip of gold foil.

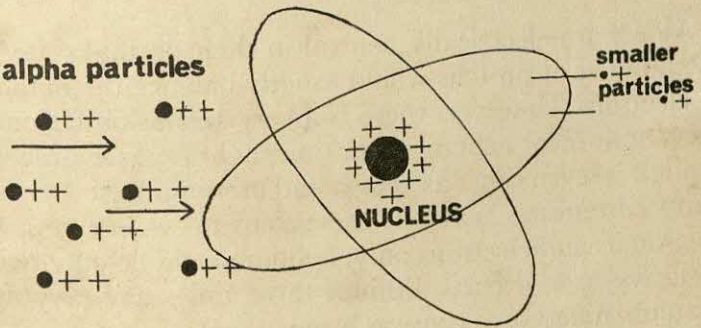


An atom is mostly space just as a solar system is mostly space.

PROTONS

Rutherford tried the effect of bombarding other elements with streams of alpha-particles. For instance, he sent alpha-particles into nitrogen gas.

As before, most of the alpha-particles passed straight through, but when a collision occurred it was found that smaller, positively-charged particles were emitted. These smaller particles, which were named *protons*, were about the same weight as a hydrogen atom and they carried a single positive charge. Evidently they were hydrogen atoms with an electron missing.

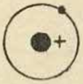


EXPERIMENTS WITH PLANTS USING RADIOISOTOPES

THE PICTURE OF THE ATOM

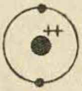
It was very tempting to picture all atoms as being made up of electrons and protons.

hydrogen



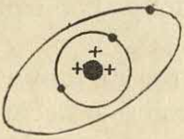
1 proton
1 electron

helium



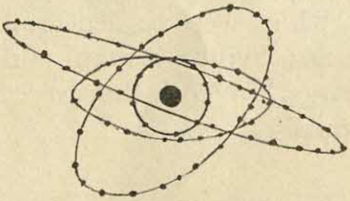
2 protons
2 electrons

lithium



3 protons
3 electrons

uranium



92 protons
92 electrons

Atoms are electrically neutral in their normal state, so the number of protons would exactly balance the number of electrons. However, there is a very serious objection to this simple idea: helium is four times as heavy as hydrogen,[1] lithium is seven times as heavy, and uranium well over two hundred times as heavy. If these elements were composed of protons and electrons only, helium would be only twice as heavy as hydrogen, lithium three times as heavy and uranium ninety-two times as heavy.

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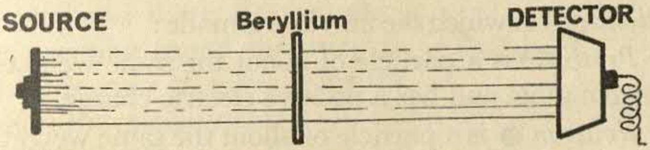
[1] The number of times an atom of a certain element is heavier than an atom of hydrogen is defined as the *atomic weight* of that element. Thus, the atomic weight of helium is about 4, the atomic weight of lithium about 7 and the atomic weight of uranium about 235.

NEUTRONS

This difficulty led scientists to guess that there must be some other particles in the nucleus. These other particles would have to be electrically neutral, and careful consideration of atomic weights seemed to indicate that they would be about the same weight as protons.

In 1930, two German scientists noticed that when alpha-particles were allowed to strike the rather rare metal beryllium, a radiation of great penetrating power was produced.



This radiation was also studied by Madame Curie's daughter, Irene, and Monsieur Joliot, her husband, but it was not until 1932 that an Englishman, James Chadwick, put forward the suggestion that the radiation consisted of particles of about the same weight as protons, but electrically neutral. He called them *neutrons* and his theory is now fully accepted.

Chadwick's discovery of neutrons made the scientist's picture of the atom much clearer.

V. STRUCTURE OF THE ATOM

AFTER carrying out a great number of very ingenious experiments, scientists have learned quite a lot about the nature of these tiny particles which are "building blocks" of atoms. Considering how very small these particles must be, it is a remarkable scientific achievement to have found out so much about them. These then are the *fundamental particles* out of which the universe is made:

The Proton ⊕ is a particle of about the same weight as a hydrogen atom and has a positive electric charge.

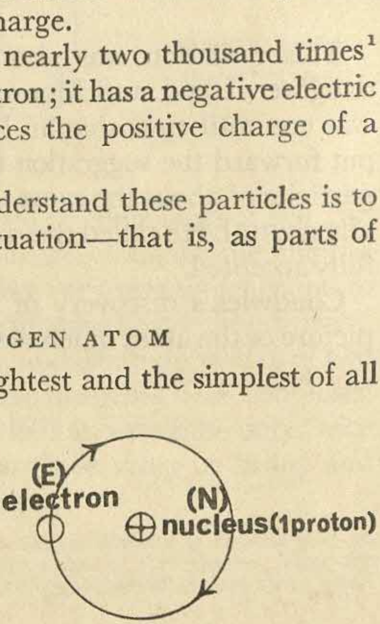
The Neutron ● is a particle of about the same weight as a proton, but it has no electric charge.

The Electron ○ is a particle nearly two thousand times[1] lighter than a proton or a neutron; it has a negative electric charge which exactly balances the positive charge of a proton.

The best way to try to understand these particles is to meet them in their usual situation—that is, as parts of atoms.

THE HYDROGEN ATOM

Hydrogen atoms are the lightest and the simplest of all atoms. A single hydrogen atom is made up of a central part, the nucleus, with an electron spinning round it. As the diagram indicates,



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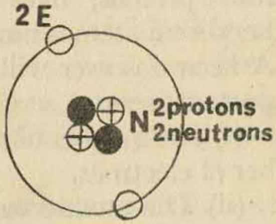
[1] 1837 times lighter, to be more exact.

the nucleus of a hydrogen atom is a single proton. The atoms of all other elements are more complicated and the hydrogen nucleus is the only nucleus which does not contain neutrons.

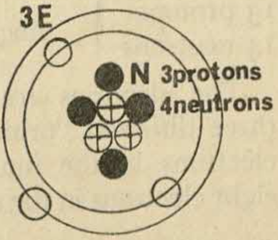
THE HELIUM ATOM

A slightly heavier atom is the helium atom. Helium gas has been used for filling balloons and airships because it is both very light and non-inflammable. The nucleus of the helium atom is composed of two protons and two neutrons, and there are two electrons spinning round the nucleus. It is fairly easy to guess from the diagram that helium atoms are about four times as heavy as hydrogen atoms.



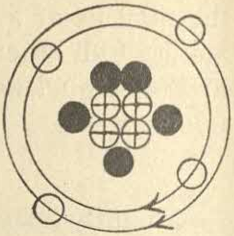
THE LITHIUM ATOM

Heavier again are the atoms of a rare metal called lithium. It is seven times as heavy as hydrogen. The nucleus is made up of three protons and four neutrons and there are three electrons spinning around the nucleus. Scientists have evidence for thinking that one of these electrons of the lithium atom is further away from the nucleus than the other two.



THE BERYLLIUM ATOM

An atom of another rare metal called beryllium can be represented by this diagram. Look carefully at the diagram and then try to answer the following questions about it:



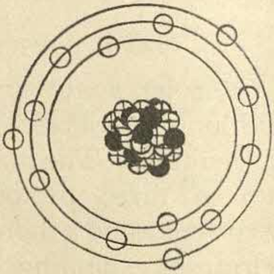
- (i) How many electrons are there?
- (ii) How many protons?
- (iii) How many neutrons?
- (iv) How many times heavier is it than an atom of hydrogen?

The answers are: four electrons, four protons, five neutrons, and a beryllium atom is nine times as heavy as a hydrogen atom. A keen observer will have noticed the following two important facts:

(i) The number of protons is always the same as the number of electrons.

(ii) The atomic weight, that is, the number of times a certain atom is heavier than a hydrogen atom, can be found by adding together all the particles in the nucleus.

THE ALUMINIUM ATOM



Atomic weight $= 27$
13 electrons
13 protons } nucleus
14 neutrons }

The electrons are arranged in three different "orbits", with two electrons in the innermost orbit, eight electrons in the second, and three in the outer one.

THE COPPER ATOM

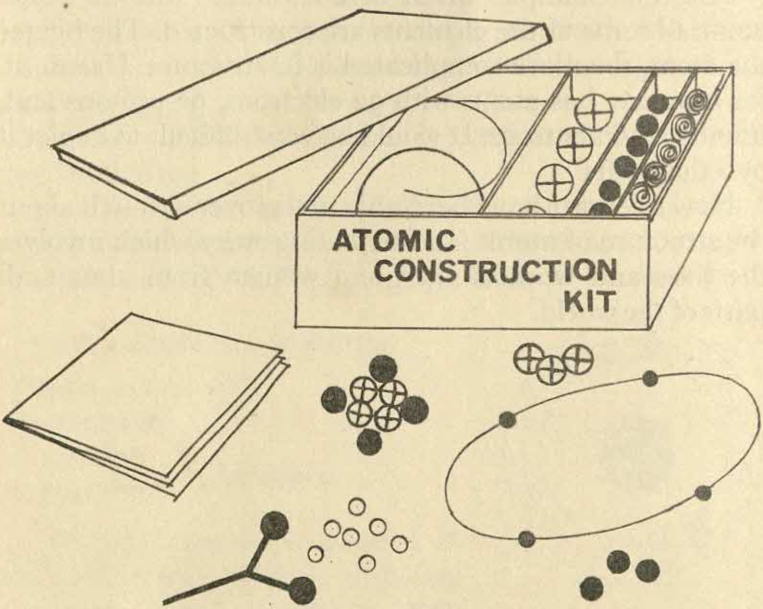
Atomic weight $= 64$
29 electrons
29 protons } nucleus
35 neutrons }

In the copper atom, the electrons are arranged in five different orbits. Actually, these diagrams are a little misleading because they seem to indicate that the electrons are all going the same way round, making the atom the same shape as a penny, that is, flat. It is customary to use the word "shell" instead of "orbit" and an atom can be imagined to be like a nut, the nucleus being the kernel and the electrons making one or more shells.

The few examples given here show the way in which atoms of some of the elements are constructed. The bigger the atom, the more complicated is its structure. Uranium, for instance, has atoms with 92 electrons, 92 protons and, usually, 146 neutrons. It would be very difficult to depict it by a diagram!

How scientists have been able to discover so much about the structure of atoms is a fascinating story which involves the lives and work of men and women from almost all parts of the world.

VI. ISOTOPES



An atomic do-it-yourself kit would contain protons ⊕, neutrons ●, and electrons ○. The protons and the neutrons have about the same weight, but electrons are about one two-thousandth (1/2000th)[1] of this.

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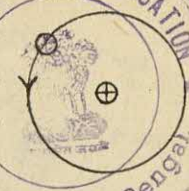
[1] To be more exact, an electron is 1/1837th of the weight of a proton.

The first model in the Instruction Book would be a *Model of a Hydrogen Atom* and it would be very simple to construct—just one proton with one electron in an orbit around it.



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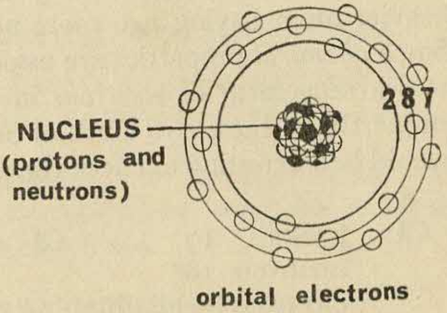
On the other hand, the *Model of a Uranium-235 Atom* would be one of the most difficult to put together.

No. 17, Model of a Chlorine Atom, would be a very good model for beginners to make.

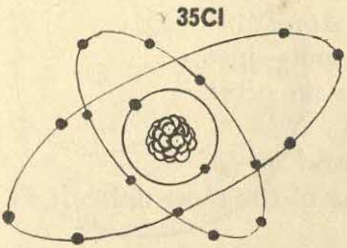
"For this model, take 17 protons, 17 electrons, and either 18 or 20 neutrons, according to the type of chlorine atom you wish to contruct," the instructions would read.

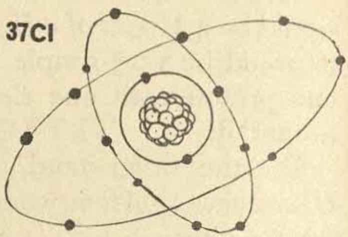


"The protons and neutrons should be fitted together to form the nucleus and then the electrons should be arranged in orbits of 2, 8 and 7, starting from the inside and working outwards." This seems fairly straightforward, but why do the instructions say "*either* 18 or 20 neutrons, according to the type of chlorine atom you wish to construct"?

The answer lies in the fact that ordinary chlorine gas is made up of two different kinds of atoms. These two types of chlorine atoms seem, at first, to be identical in every way: their chemical properties are exactly the same. However, they differ very slightly in weight. The lighter kind has an atomic weight of 35 and the heavier kind an atomic weight of 37.

Here are the two models of chlorine. They are exactly

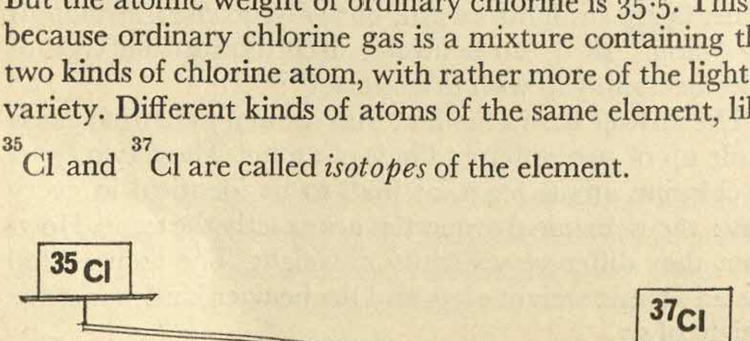




the same outside but are slightly different inside, the heavier atom having two more neutrons than the other. Since *chemical* properties are associated with the number and arrangement of *electrons* in an atom, the chemical properties of these two kinds of chlorine are identical. It would be interesting to check the atomic weights of each:

^{35}Cl	protons	17	^{37}Cl	protons	17
	neutrons	18		neutrons	20
	electrons	negligible		electrons	negligible
		35			37

But the atomic weight of ordinary chlorine is 35·5. This is because ordinary chlorine gas is a mixture containing the two kinds of chlorine atom, with rather more of the lighter variety. Different kinds of atoms of the same element, like ^{35}Cl and ^{37}Cl are called *isotopes* of the element.



ISOTOPES OF URANIUM

Uranium has three naturally occurring isotopes, ^{238}U, ^{235}U and ^{234}U. In order to build models of these atoms with the construction kit, we should require:

92 *protons*
92 *electrons*

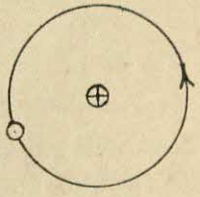
but the number of neutrons would vary slightly.

^{238}U would require $238 - 92 =$ *146 neutrons*
^{235}U would require $235 - 92 =$ *143 neutrons*
^{234}U would require $234 - 92 =$ *142 neutrons*

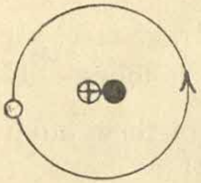
If a person were asked whether he would rather carry a bucket of ^{238}U or a bucket of ^{235}U he might choose the lighter of the two, but most likely he would answer that there would not be much difference.

HEAVY HYDROGEN AND HEAVY WATER

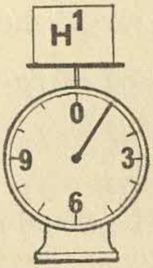
There is a lot of water in all the world—all the seas and oceans, rivers and lakes, all the ice and snow at the North and South Poles, the moisture in the atmosphere, to mention only the most obvious sources of water. About one part in every 5000 parts of water is "heavy water"—that is to say, instead of being composed of ordinary hydrogen and oxygen, H_2O, it is composed of "heavy hydrogen" and oxygen.

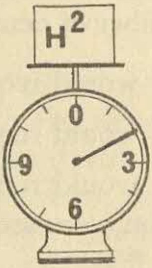


Ordinary hydrogen has a very simple structure, 1 electron spinning around a single proton. What then is "heavy hydrogen"? It has one electron and one proton but, in addition, its nucleus contains one neutron. The atomic



weight of ordinary hydrogen, H^1, is 1. The atomic weight of heavy hydrogen, H^2, is 2. Therefore heavy hydrogen weighs *twice* as much as ordinary hydrogen. Its chemical properties are exactly the same as ordinary hydrogen: it has no

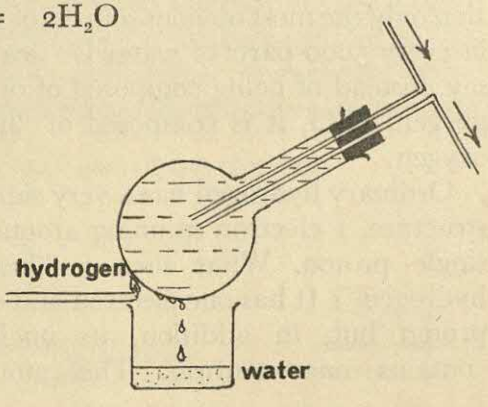




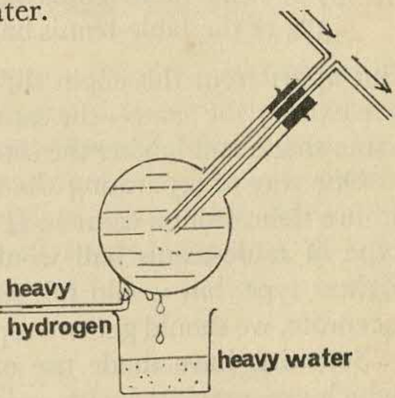
colour, taste or smell, it will burn with a pale blue flame and it forms an explosive mixture with air or oxygen.

When ordinary hydrogen is burned in air, it combines with oxygen in the air to form water. The chemical equation for this is:

$$\begin{array}{ccccc} \text{hydrogen} & & \text{oxygen} & & \text{water} \\ 2H_2 & + & O_2 & = & 2H_2O \end{array}$$



If a jet of burning hydrogen is allowed to come in contact with a cold surface, like a flask kept cool by running tap water, the moisture will collect in drops. These drops may be collected in a beaker and a few simple experiments will confirm that the liquid is water.



If this experiment could be repeated using "heavy hydrogen" instead of ordinary hydrogen, drops of "heavy water" would be produced. If you were to drink a glass of this "heavy water" (probably the world's most expensive drink!) there would be no difference between its taste and that of ordinary water. The chemical properties of "heavy water" are no different from ordinary water.

Deuterium

The heavy isotope of hydrogen is so interesting to atomic scientists that it has been given a special name: it is called *deuterium*. Its atomic weight is 2. Sometimes its symbol is written ^{2}H, or more usually as D.

CAN ISOTOPES BE SEPARATED?

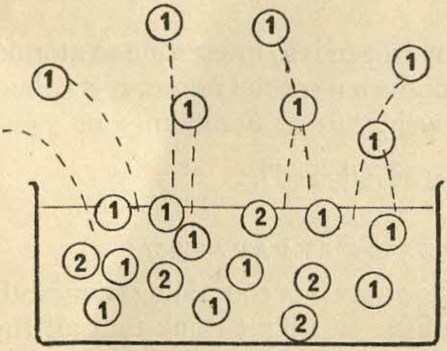
Suppose we have an enormous box containing thousands of table-tennis balls. At first, we might think that all the balls are identical with each other, but it could be the case that three out of every hundred are slightly heavier than the others.

97% of the table-tennis balls weigh 1 gram.
3% of the table-tennis balls weigh 1 1/10 grams.

But apart from this slight difference in weight, the balls are exactly the same—the same colour, the same size, the same shape and having the same amount of bounce.

One way of separating the two kinds of balls might be to fire them from a cannon. If this were done, the heavier type of table-tennis ball would not travel as far as the lighter type, but would fall short and, if the firing were accurate, we should get two separate piles.

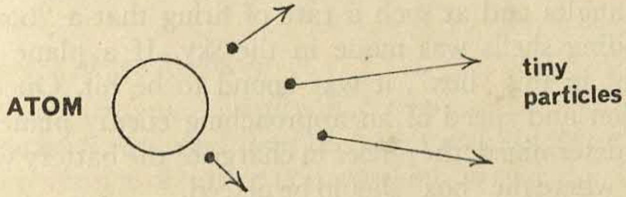
Scientists have made use of those *physical* properties which are associated with weight of atoms (boiling points and rates of gaseous diffusion, for instance) to separate isotopes of the same element. Thus, heavy hydrogen (deuterium) has been separated from the lighter isotope by compressing ordinary hydrogen gas to a liquid at very low temperatures and then allowing it to evaporate slowly. The lighter isotope of hydrogen evaporates first and the remaining liquid is richer in the heavier isotope.



There seems to be no end to the puzzles of nature, but the answer to the riddle *"When is hydrogen not hydrogen?"* could be *"When it's deuterium!"*

VII. ATOM SMASHING

By the beginning of this century, scientists had begun to realise that atoms were not the hard, round "bricks" which had been imagined by Democritus and John Dalton. Experiments with electrical discharges, with X-rays and with radioactive substances like radium seemed to indicate that tiny bits could be chipped off atoms. Moreover, the experiments of Rutherford, Chadwick and others[1] led to the realisation that atoms are made up of more than one kind of constituent and that they have definite structures. A scientist who had escaped from Nazi Germany, Lise Meitner,[2] first saw the practical possibility of splitting an atom into two more or less equal pieces. She knew that this was a daring suggestion because to succeed would destroy for ever any lingering idea that atoms were the fundamental particles out of which the universe is made.



But, one may ask, how does a scientist tackle the job of trying to split an atom when the largest atom is about *one-millionth* of the size of a full stop on this page.

. ←— size of a group of about one million atoms.

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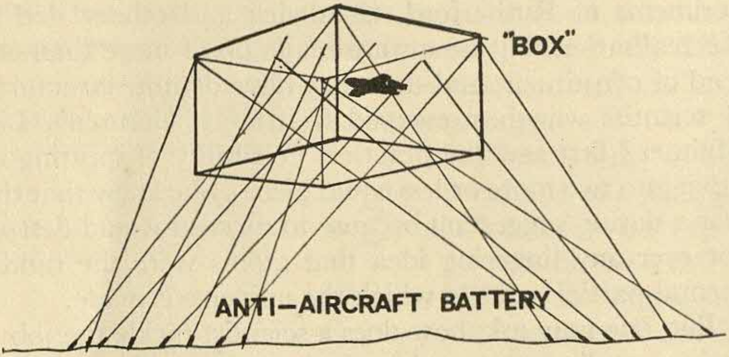
[1] See pp. 45–51.

[2] See pp. 21–22.

HOW TO HIT A SMALL TARGET

The problem of splitting the atom is similar in some respects to trying to shoot down an aeroplane with an anti-aircraft gun. At the beginning of World War II, anti-aircraft gunners were not very successful at shooting down enemy bombers. To a gunner at that time, it must have seemed an impossible task to find the target which often appeared as a mere pin-point in the sky. Then some scientists worked out a system of firing which they said could not possibly miss the target. It was really a very simple plan; instead of the gunners taking individual "pot-shots", a battery of gunners in calculated positions sent up shells at such angles and at such a rate of firing that a "box" of exploding shells was made in the sky. If a plane were caught in this "box", it was bound to be hit. Once the position and speed of an approaching enemy plane had been determined, the officer in charge of the battery would know where the "box" should be placed.



This technique of firing proved so successful that enemy bombers had to fly very high indeed to avoid being shot down.

The simple lesson to be learnt from this is that even a very small target is bound to be hit if a sufficiently large number of "shells" is fired at it at a time.

THE RAY GUN

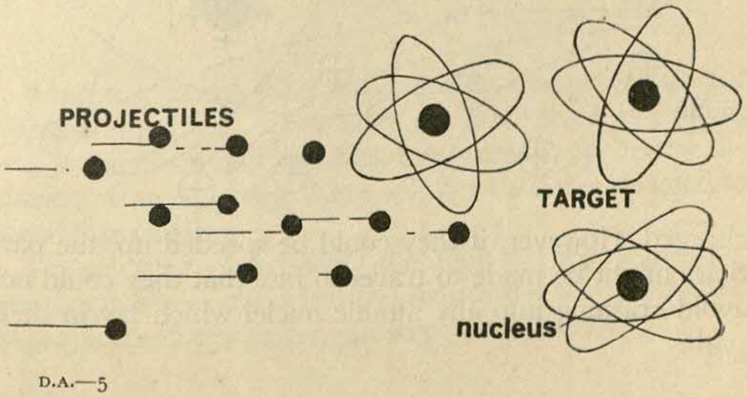
It became clear to atomic scientists that they would need to construct a sort of "ray gun" capable of firing a tremendous number of small, invisible bullets into a target. These "bullets" would have to be even smaller than the atoms which would be the targets. How could this be done? Could the particles which are given out by radioactive substances be shot into some uranium atoms? This was tried, but it was soon found that these particles were not very suitable. Those which were proved to be successful were neutrons.

Efficiency of the Ray Gun

By 1932, atomic scientists had come to the conclusion that at least two conditions must be satisfied before there was any chance of hitting and smashing atoms:

(1) A large number of projectiles would have to be fired at the target at the same time.

(2) The projectiles should be moving fast enough to have sufficient energy to penetrate to the very core of the atom and make a direct hit on the nucleus.

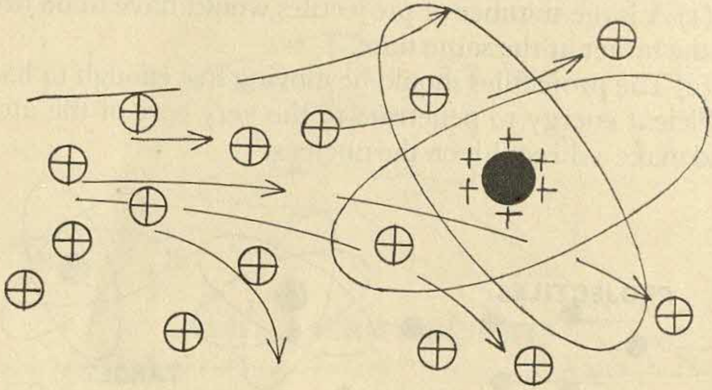


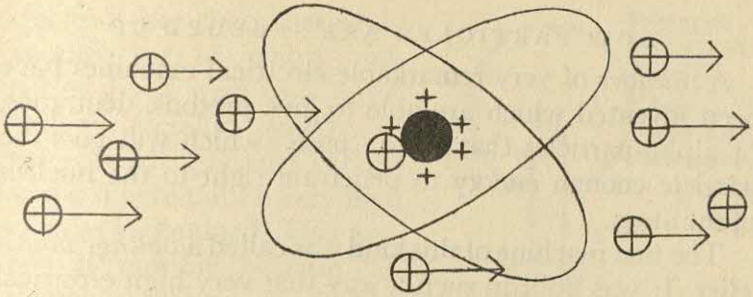
THE PROJECTILES

Another problem was to find suitable projectiles or "bullets" to fire at suitable atoms. As the projectiles would have to be smaller than the atoms which would be the targets, there was not a great deal of choice. The scientists considered the possibilities:

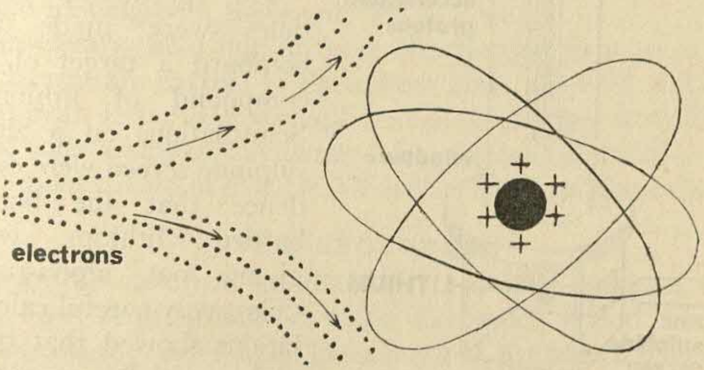
Protons,
Deuterons,
Alpha-particles,
Electrons
and
Neutrons.

Protons are the nuclei of ordinary hydrogen atoms; deuterons are the nuclei of heavy-hydrogen atoms; alpha-particles are nuclei of helium atoms. These three types of particles are positively charged and therefore tend to be repelled by the nucleus of an atom, which is also positively charged. However, if they could be speeded up, the particles might be made to travel so fast that they could not avoid crashing into any atomic nuclei which lay in their path.





What about the other particles on the list? Electrons are not very suitable for atom smashing: they are much too small and, as they are negatively charged, they would tend to be repelled by the outer "shell" of an atom.



Neutrons, on the other hand, are the best projectiles for bombarding atoms. They have the same mass as protons and, being electrically neutral, they are not repelled by the nucleus. Consequently, there will not be the same need to speed them up first.

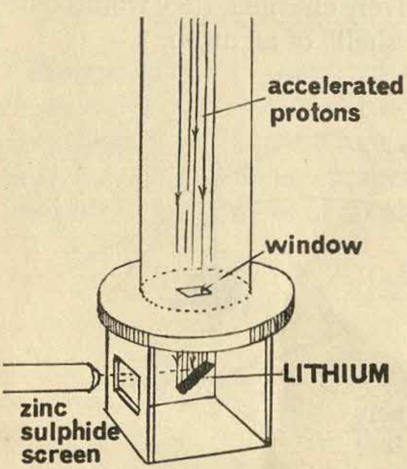
At one time or another, the four particles—protons, deuterons, alpha-particles, and neutrons—have been used as projectiles for exploring the structure of atoms.

HOW PARTICLES ARE SPEEDED UP

A number of very remarkable electrical machines have been invented which are able to give protons, deuterons, or alpha-particles that extra "push" which will give the particle enough energy to penetrate right to the nucleus of the atom.

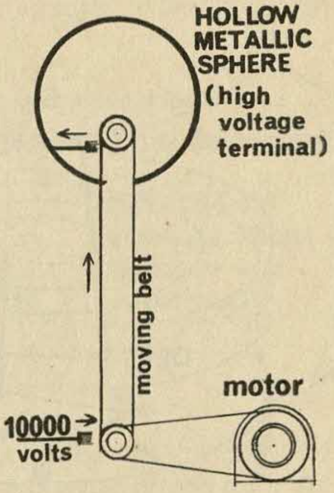
The first machine of this kind was called a *voltage multiplier*. It was built in such a way that very high electrical voltages could be obtained. It was used to accelerate protons that were then sent into a strip of lithium, which is a metal. This was one of the first attempts at atom-smashing and the result was very interesting.

The speeded-up particles were made to bombard a target of a compound of lithium. Scintillations on a zinc sulphide screen were evidence that the bombarded lithium was giving out alpha-particles; very careful calculations showed that two alpha-particles were released for every proton which made a hit.



THE VAN DE GRAAFF GENERATOR

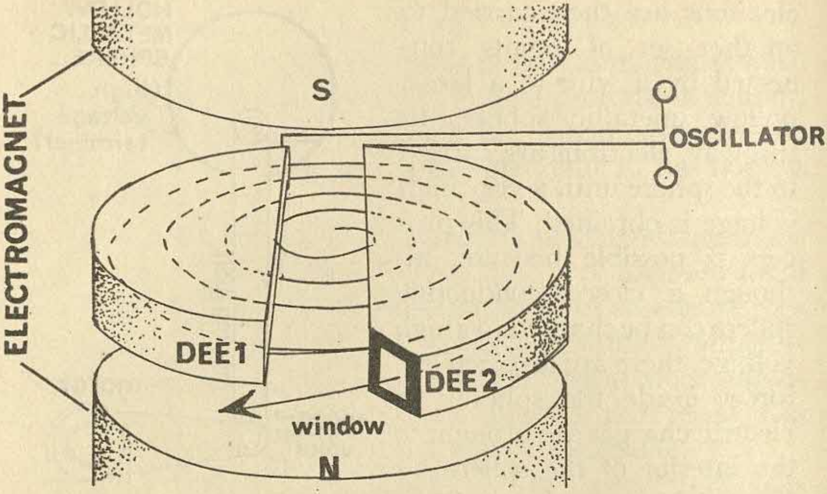
Another interesting and very spectacular atom-smashing machine is the *Van de Graaff Generator*. The principle of this machine is not difficult to understand. A set of charged points, arranged like the teeth of a comb, spray electrons from a low-voltage generator on to a moving belt. The



electrons are then carried to another set of points connected by a wire to a large, hollow, metallic sphere. In this way, electrons are carried to the sphere until a very high voltage is obtained. This process is possible because, although a closed conducting sphere can be charged to a high voltage, there are no electrical forces inside the sphere. As electric charges are brought to the interior of the sphere by the moving belt, there will be an electric field due to those charges, but as soon as the charges are carried to the sphere itself, the field will disappear. Eventually, the sphere can be charged to millions of volts. Using this machine, it is possible to produce a continuous stream of particles all accelerated to a high voltage.

THE CYCLOTRON

In the *cyclotron*, another atom-smashing machine, two hollow, semi-circular metallic electrodes, called "dees" because they are shaped like a letter D, are placed between the poles of a powerful electromagnet. The dees are so arranged that there is a gap between their straight sides and they are connected to the terminals of an oscillator, by which device the voltage is made to alternate from one dee to the other. The charged particles are fed in at the centre of the gap between the two dees. When Dee 1 is negative and Dee 2 is positive, these charged particles are accelerated into the space inside Dee 1. There the electric field disappears but the magnetic field caused by the electro-

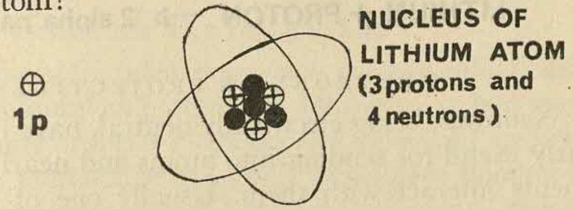


magnet remains unchanged because the dees are made of a non-magnetic metal. Inside Dee 1, the magnetic field guides the charged particles along a semi-circular path. As the particles emerge from this dee, the oscillator reverses the polarity and the particles are accelerated across the gap and enter Dee 2. The process continues and, after many revolutions, the charged particles will be moving in a circular path almost as large as the dees. The particles are then deflected from their circular path by a charged plate (not shown in the diagram), so that they shoot out of a small window. The stream of highly accelerated particles can then be directed at the target.

The final speed of the particles will depend to a very great extent on the size of the cyclotron. The particles go faster and faster as they move in ever-widening spirals, so the larger the diameter of the dees, the greater will be the final speed of the particles. The first cyclotron was only eleven inches across, but scientists and engineers soon set about the task of making larger ones. There are cyclotrons in existence now with diameters measured in feet and even in yards.

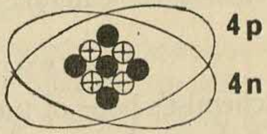
SOME RESULTS OF ATOM SMASHING

What happens if, for example, a proton hits the nucleus of a lithium atom?

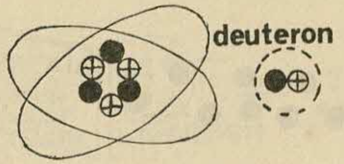


There are several possibilities.

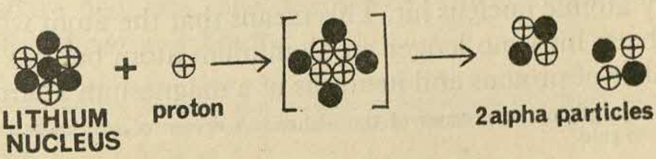
(1) The proton could just stick to the nucleus, but this would mean that there would be one more proton than the number of electrons, so that the atom would no longer be electrically neutral.



(2) A deuteron could be "knocked out" and the resulting nucleus would have one less neutron.



(3) One or two alpha-particles could be formed.



Actually, in one of the first attempts to send speeded-up particles into atoms, a stream of speeded-up protons was sent into a film of lithium, and it was found that for every proton which made a hit, two alpha-particles were released.

LITHIUM + PROTON → 2 alpha particles

NEUTRONS AS PROJECTILES

Neutrons, being electrically neutral, have been particularly useful for sending into atoms and nearly all the elements interact with them. Usually one of three things happens as a result of neutron bombardment:

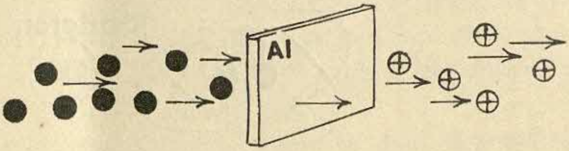
(1) The element can change into another element; this is called transmutation.[1]

(2) The element can become radioactive.

(3) Nuclear fission can take place.

TRANSMUTATION

The alchemist's hope of turning base metals into gold is still only a dream, but atomic scientists have succeeded in changing one element into another. Transmutation has become a reality. If a stream of neutrons is sent into a film of aluminium metal, protons are given out, one proton for every atomic nucleus hit. This means that the atom which has been hit is no longer an aluminium atom but has the number of protons and neutrons of a magnesium atom.



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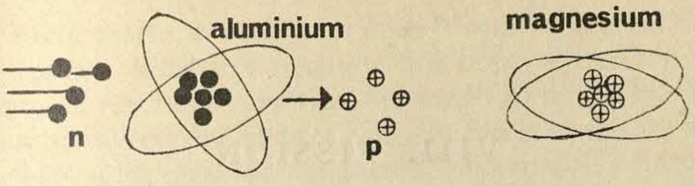
[1] See p. 36 for an account of the alchemist's dream of transmutation of lead into gold.

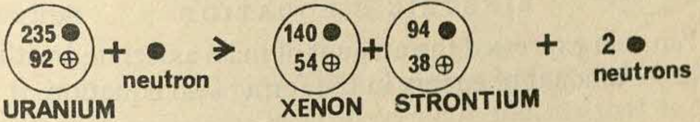


INDUCED RADIOACTIVITY

There are very few elements which are naturally radioactive like radium and uranium. However, it has been found that quite ordinary elements, like iodine and carbon, can be made radioactive as a result of neutron bombardment. Ordinary iodine which has been subjected to rays of neutrons becomes radioactive. This kind of radioactivity is called *induced radioactivity* and is one of the most interesting results of "atom smashing".

FISSION

The most exciting result of bombarding atoms with neutrons is *nuclear fission*, that is, splitting the atom into two more or less equal parts. Thus a direct hit on a uranium nucleus (containing 92 protons and 143 neutrons) breaks it in two to give xenon and strontium[1] as well as releasing some "unwanted" neutrons. After absorbing a neutron, the uranium nucleus splits into two fragments and releases the extra neutrons. The discovery of this basic fact made possible the atomic bomb.



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[1] This is simplified. Fission of uranium yields a whole distribution of products, also the products (e.g. isotopes of strontium) are highly unstable (i.e. "excited") and they soon give out more particles forming more stable products.

VIII. FISSION

MATTER AND ENERGY

THE universe is composed of *matter* and *radiant energy*. Matter consists of substances around us, like rocks, wood, water, air, grass: in short, all solids, liquids and gases. In addition to matter, the universe contains energy in the form of light, X-rays, radio waves and other radiations. What is the difference between *matter* and *energy*? At one time scientists thought that matter had a property called *mass* which accounted for its weight, but that energy possessed no mass and was weightless. Then, in 1905, Albert Einstein was able to show that energy also has mass, so that light was attracted to matter through gravitation just as a falling apple is pulled to the earth through gravitation. This view has been confirmed by astronomers, who have found that light travelling from a distant star to the earth and passing close to the sun is pulled towards the sun by its gravitational attraction.

EINSTEIN'S EQUATION

Einstein expressed the amount of mass associated with a definite amount of energy in the form of an equation

$$\mathrm{E} = mc^2$$

where E represents the amount of energy, m is the mass, and c is the velocity of light.[1] Light travels very fast, so c is a very large number and the equation states:

Amount of energy = mass × a very large number.

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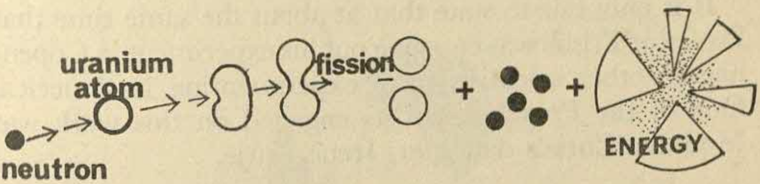
[1] The speed of light is a *fixed* speed, calculated as 186,000 miles per second.

In other words, a very small mass is equal to a great deal of energy. Einstein's equation has been verified by the study of reactions involving the nuclei of atoms like the ones discussed in Section VII. In nuclear fission, the nucleus splits into two fragments, plus several neutrons, and during this process a very small amount of "unwanted" mass of the nucleus is converted into a very large amount of energy which is released.

A DATE TO REMEMBER

The year 1939 will certainly be recorded in history books of the future because of two great events which took place then. It was in September 1939 that Adolf Hitler's troops marched into Poland and the Second World War broke out; earlier in that year, scientists all over the world had been excited by the news that the uranium atom had been split into two more or less equal parts. This splitting of the uranium atom is called *uranium fission*.



It is easy to see why scientists were so excited by this news: it provided the most compelling evidence that atoms could not possibly be the final "bricks" out of which the universe is constructed. Of course, the discoveries of Becquerel, Madame Curie, Rutherford, Chadwick and others had demonstrated the same thing, but actually to split an atom into two provided the most convincing evidence of all.

URANIUM FISSION

The credit of being the first to split the uranium atom goes to Professor O. R. Frisch and Dr. Lise Meitner.[1] The experiment was actually carried out during the last month of 1938, but the results were not published until the beginning of 1939. A small amount of uranium was placed in a special container called an ionisation chamber, which was connected up to an instrument able to show the amount of energy given out by a reaction. A sort of ray gun bombarded the uranium with neutrons. Professor Frisch described the experiment like this:

> "In a couple of days I had got the necessary equipment together; a very simple ionisation chamber (two metal plates separated by a glass ring), a valve amplifier, and a register set to record the amplified pulses of ionisation . . . As soon as I had the apparatus together the pulses came: not many, a few a minute, but unmistakable by their great size."

It is only fair to state that at about the same time that Professor Frisch was carrying out his experiment in Copenhagen, other scientists were experimenting in America. One of the French scientists engaged on this work was Madame Curie's daughter, Irene Curie.

RELEASE OF ENERGY

All these scientists noticed the same thing: that when a tiny atom is split, a lot of energy is released at the same time. If one atom could give that amount of energy, how much energy would be given off if, say, all the atoms in a lump of uranium the size of a cricket ball were all split at the same time? It was not long before atomic scientists knew the terrifying answers to this question.

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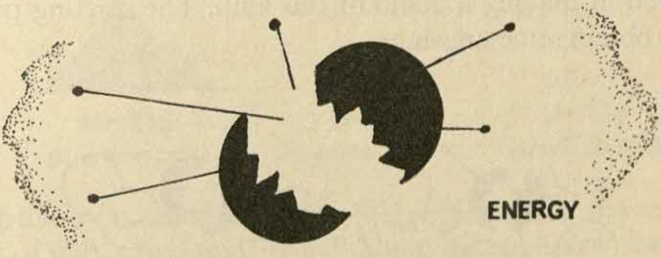
[1] For the story of Professor Frisch's experiment see pp. 23–4.

IX. MAKING AN ATOMIC BOMB

Otto Frisch first demonstrated nuclear fission on a very small scale in December 1938.[1] More than six fateful years were to elapse before a single atomic bomb devastated Hiroshima. Scientists of many nations contributed their knowledge and skill to the making of the first atomic bomb and, although they had many great obstacles to overcome, the principle by which it worked is fairly easy to understand.

THE CHAIN REACTION

When a neutron penetrates the nucleus of a uranium atom, fission results, and, in addition to the two "halves", several more neutrons are released with considerable energy. Flying out of the nucleus at a great speed, these neutrons shoot into other uranium atoms which lie in their path. If each neutron makes a "hit", more uranium atoms will be shattered, releasing more high-speed neutrons and a lot of energy.



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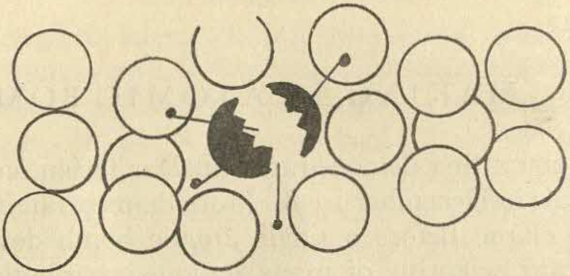
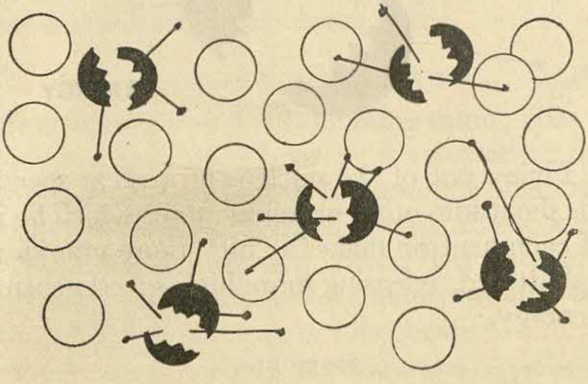
[1] See pp. 21–4.



In this way, more and more uranium atoms are shattered and so more and more neutrons are produced, setting up a *chain reaction*. In less than a second, *billions* of uranium atoms are shattered and with each hit, part of the mass of the atom is changed into energy. The total energy released causes a terrific explosion. It was an atomic explosion of this type which virtually destroyed Hiroshima.

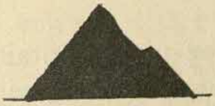
Let us examine some of the most important steps involved in making a bomb of this kind. The starting point is to obtain some uranium.



LOOKING FOR URANIUM

Uranium is hard to find. Some of the best deposits of ore are in the Congo, Australia and in Northern Canada, so the cost of transporting the ore to Europe and America is very great. After all, most of the ore is worthless stone and clay containing only very small amounts of uranium itself—perhaps two or three pounds of uranium per ton of ore. Moreover, the ore does not contain pure uranium: it is usually present combined with oxygen as uranium dioxide, UO_2. After many intricate and costly chemical processes, the oxygen is removed and pure uranium is obtained. It is a shiny hard material which is heavier than lead. Uranium is not dangerous to touch or handle and, on the whole, its properties are similar to those of other metals like lead, silver and gold. It can be melted and cast into ingots, rolled into long rods, or cut up into bars.

WHICH ISOTOPE?



U–238
(approx. 99·3%)

U–235
(approx. 0·7%)

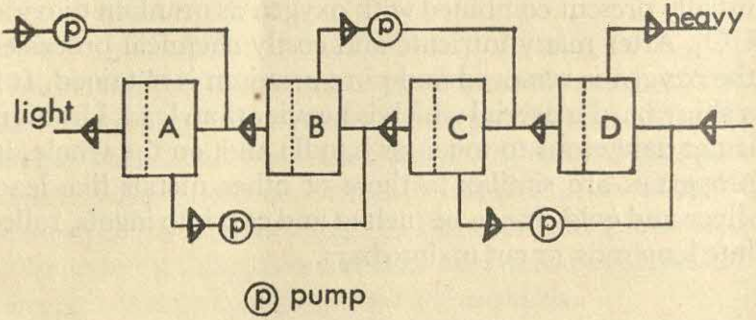
U–234
(approx. 0·006%)

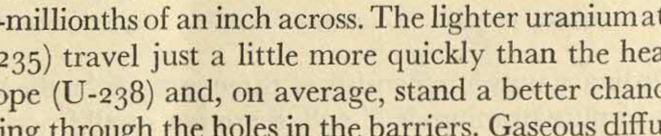
Ordinary uranium consists of three isotopes[1]: the main bulk of pure uranium is U-238, there is a small fraction of U-235 and just a trace of U-234. As luck would have it, U-238 is not very suitable for fission and U-235 must be used. This means that from a ton of ore, only a fraction of an ounce of suitable uranium is available. Moreover, it is a difficult and expensive process to try to separate the isotopes from each other.

[1] See pp. 56–62.

SEPARATION OF THE ISOTOPES

There is a very slight difference in weight between U-238 and U-235; scientists seized upon this slight difference as a means of finding a method by which they could be separated from each other. Eventually, they evolved the *Gaseous Diffusion Process*. Uranium is converted into a gas and then pumped through long pipes containing a series of *barriers*. These "barriers" are like sieves with tiny holes in them, but the holes are extremely small, less than two-millionths of an inch across. The lighter uranium atoms (U-235) travel just a little more quickly than the heavier isotope (U-238) and, on average, stand a better chance of getting through the holes in the barriers. Gaseous diffusion





plants are very large and have miles of pipes, so by the time the uranium gas has passed through thousands of these barriers, the lighter isotopes will be well ahead of the others. In this way, the lighter atoms of U-235 become more and more plentiful and can be taken off at the end of the line in a pure form. The U-238 is not wasted but is used for another purpose.

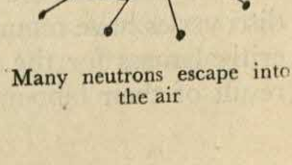
"HEX"

It is difficult to imagine uranium, one of the heaviest and hardest metals, in the form of a gas. Yet it must be changed into a gas if its isotopes are to be separated. A chemical process makes uranium combine with a very reactive element called fluorine and the gas *uranium hexafluoride* is formed. It is this gas, nicknamed "hex" by atomic scientists, which is pumped through the gaseous diffusion plant. Another chemical reaction changes the "hex" back into uranium after the isotopes have been separated.

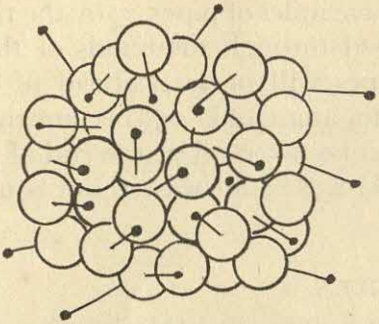
WHAT MAKES THE BOMB EXPLODE?

There are several kinds of atomic bombs and the mechanisms which set them off may differ. However, an important principle underlies all "atomic" explosions: the idea of the *critical mass.*

With a small piece of uranium, many of the neutrons given out during fission escape into the air and therefore do not cause further fission. As long as the number of neutrons lost by escape and by further fission is slightly more than the number produced by fission, no chain



Many neutrons escape into the air



Most neutrons collide with other atoms

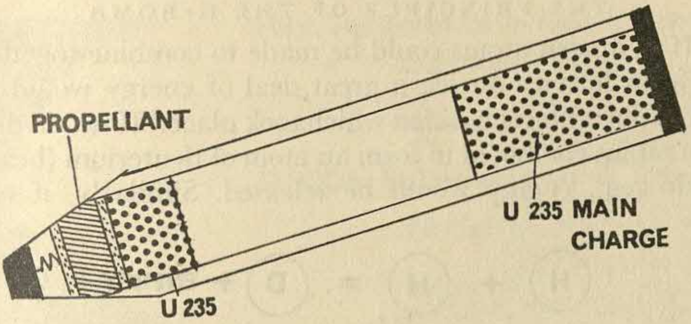
reaction will be set up and no explosion will take place.

The larger the piece of uranium, the more neutrons are trapped inside the lump and the smaller is the fraction of them which escape. Above a certain size, a chain reaction is set up and there is an explosion. The particular size above which chain reactions and explosions take place is called the *critical size* or the *critical mass.*

Essentially, therefore, an atomic bomb is a device for rapidly bringing together enough pure U-235 (or other fissionable material) to exceed the critical mass. Imagine a piece of U-235 just smaller than the critical size. This will not explode if a few neutrons are sent into it. Then imagine a smaller fragment of the same material at some distance. It too will not explode. If, however, the two pieces are brought together, the two would form a mass well above the critical size.

WHAT IS A CRITICAL SIZE?

This is the important question which worried atomic scientists engaged on making the first atomic bombs during the last phase of the Second World War. Most of their discoveries have remained secret, but it is known that the critical mass for the first bomb was a few pounds. The result of their labours brought death and devastation to



Hiroshima and Nagasaki, and gave mankind the means of self-destruction.

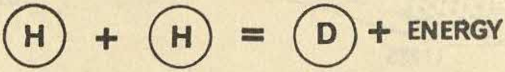
One way of exploding an atomic bomb would be for the main charge of U-235 or other fissionable material to be at one end of a shell and a smaller charge at the other. The larger amount of U-235 would be slightly less than the critical mass, so that the addition of a small amount extra would increase it sufficiently to set up a chain reaction and cause it to explode.

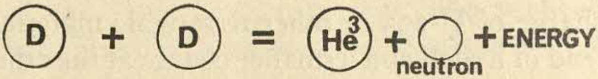
THE HYDROGEN BOMB

Since the end of the war, the Great Powers of the world have engaged in an armaments race and have striven to build bigger and better bombs. Wise and good men have pointed out the folly and wickedness of this policy and there have been many attempts to outlaw atomic warfare and to put atomic research under international control. In spite of these efforts, the nations have not yet been able to trust each other, and the race for more and more powerful means of destruction continues. One of the deadliest weapons which has been produced is the H-bomb or hydrogen bomb.

THE PRINCIPLE OF THE H-BOMB

If hydrogen atoms could be made to combine together to form heavier nuclei, a great deal of energy would be given out with each *fusion* which took place.[1] If two hydrogen atoms combined to form an atom of deuterium (heavy hydrogen), energy would be released. Similarly, if two deuterium atoms could be made to fuse together into a helium atom, more energy would be set free. Scientists have dreamed of the possibility of obtaining vast quantities of energy by making hydrogen atoms combine together but have been held up in their experiments because enormously high temperatures are required before the reactions can be started off. Once started, the reactions would be able to proceed on their own. But the explosion of an atomic bomb of the kind dropped on Japan could produce temperatures of up to 50 million degrees and possibly larger atomic bombs could create even greater temperatures.





The first hydrogen bomb, let off in 1952, is believed to have contained a mixture of deuterium and tritium, both isotopes of hydrogen. The idea seems to have been for the high temperature of an ordinary atomic bomb explosion to set off the main reaction. The result of this would be the

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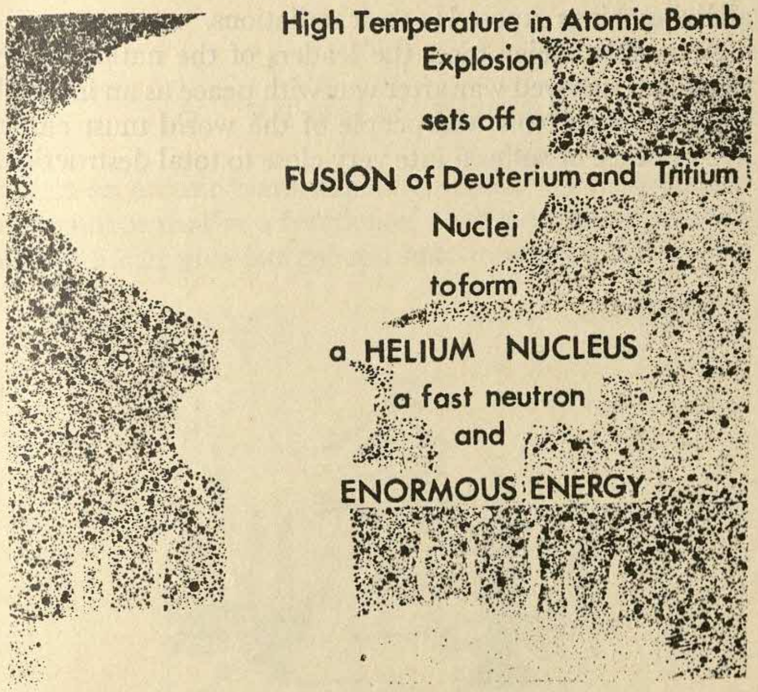
[1] See p. 115.



fusing together of deuterium and tritium nuclei and in the process a fast neutron would be released, as well as an enormous amount of energy.

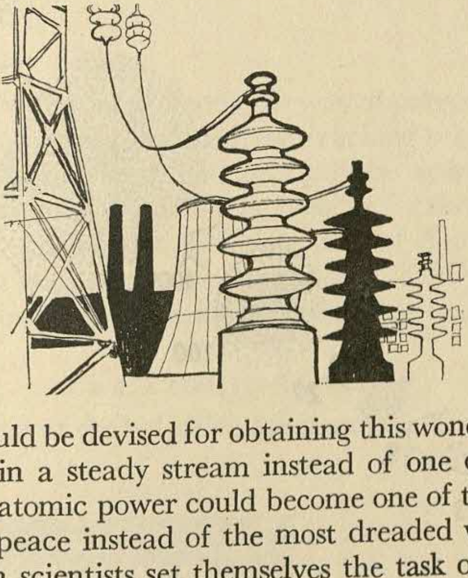
The first hydrogen bomb was so powerful that it completely destroyed the small island on which it was detonated. It has been estimated that it was about 200 times as powerful as the bomb dropped on Hiroshima.

If hundreds or thousands of these "superbombs" were to be used in a full-scale war, it is likely that all the big cities and main centres of population would be completely wiped out. Apart from this immediate destruction, the radioactive "fall-out" would remain a constant danger to all living things exposed to their radiations.

A terrible choice faces the leaders of the nations. The world has survived war after war with peace as an interval between wars. Now, the people of the world must either live in peace or suffer a fate very close to total destruction.

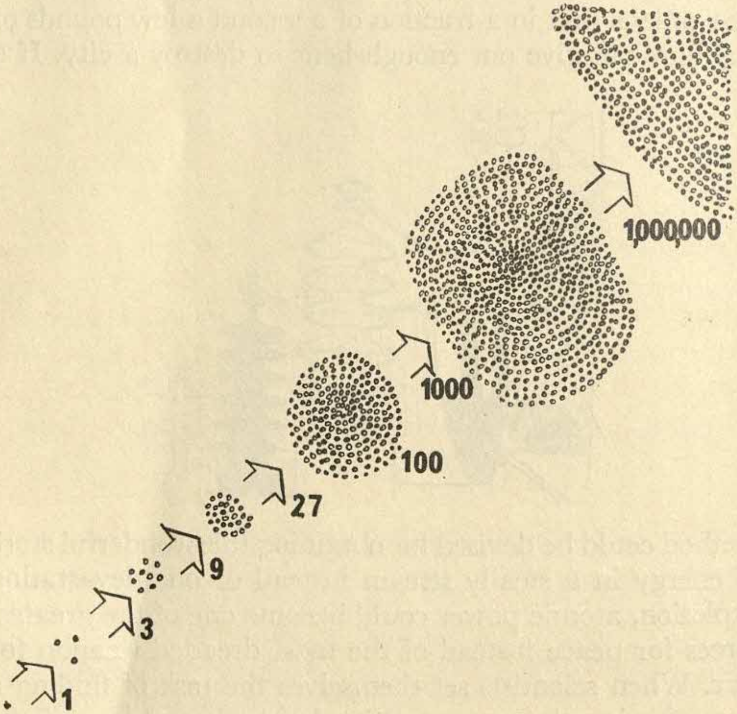
X. ATOMIC POWER

WHEN an atomic bomb explodes, the energy released is so tremendous that in a fraction of a second a few pounds of uranium can give out enough heat to destroy a city. If a method could be devised for obtaining this wonderful store of energy in a steady stream instead of one devastating explosion, atomic power could become one of the greatest forces for peace instead of the most dreaded weapon for war. When scientists set themselves the task of finding a way of using the energy which binds the nucleus of the atom together, they soon realised that a method for slowing down the chain reaction would have to be invented.

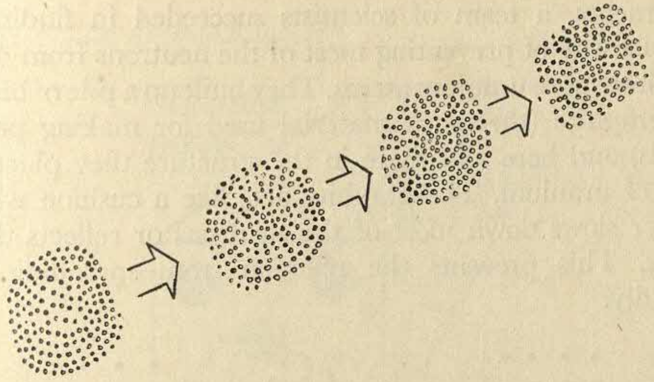


THE CHAIN REACTION

When an atom of U-235 is split by a bombarding neutron, several neutrons from the nucleus of the atom are set free. These neutrons may themselves shoot into near-by uranium atoms, and if all of them are split, many neutrons will be liberated from their nuclei. All these can now go flying off to split further uranium atoms. This happens



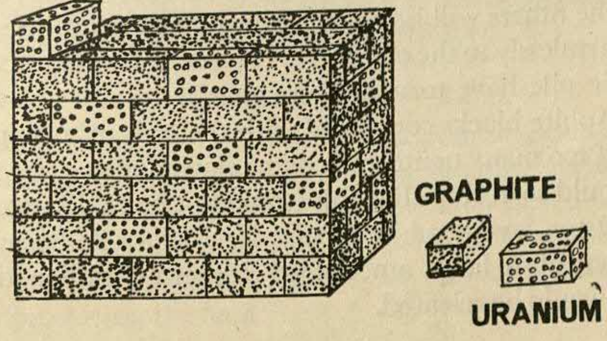
very quickly, and in less than a second, thousands, millions and *billions* of atoms will have been shattered and all the nuclear energy released results in an atomic explosion of incredible magnitude and power.



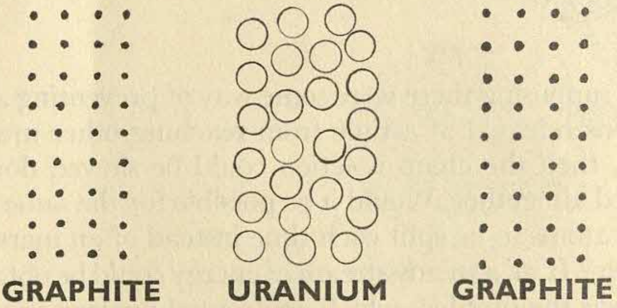
But supposing there were some way of preventing all the neutrons released at a time from reaching other uranium nuclei, then the chain reaction could be slowed down or stopped altogether. Would it be possible for the same number of atoms to be split each time instead of an increasing number? If so, a steady stream of energy could be obtained. This was the problem which confronted nuclear scientists.

THE ATOMIC REACTOR

After a great deal of calculation and many series of ex-

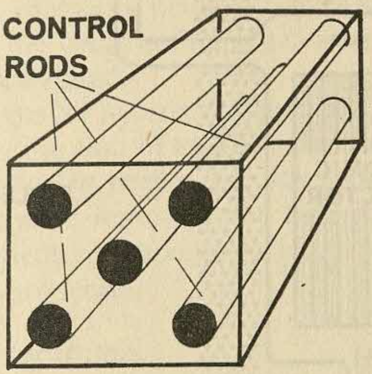


periments, a team of scientists succeeded in finding a simple way of preventing most of the neutrons from darting into more uranium atoms. They built up a pile of blocks of graphite (the black material used for making pencil leads) and here and there in the structure they placed a rod of uranium. The graphite acts like a cushion which either slows down most of the neutrons or reflects them back. This prevents the reaction from spreading too rapidly.



If the quantity and arrangement of the graphite and uranium is just right, some of the neutrons will wander around the pile until they meet a uranium atom and split it. This atom will then begin to liberate more neutrons, but most of the others will be slowed down by the graphite or escape harmlessly to the outside. Of course, the designers of an atomic pile have to make sure that there are not too many graphite blocks compared with the rods of uranium because if too many neutrons became slowed down, the reaction would soon stop. But this would not be so disastrous as having too few graphite blocks, for if the pile became out of control, a large amount of dangerous radioactive material would be released.

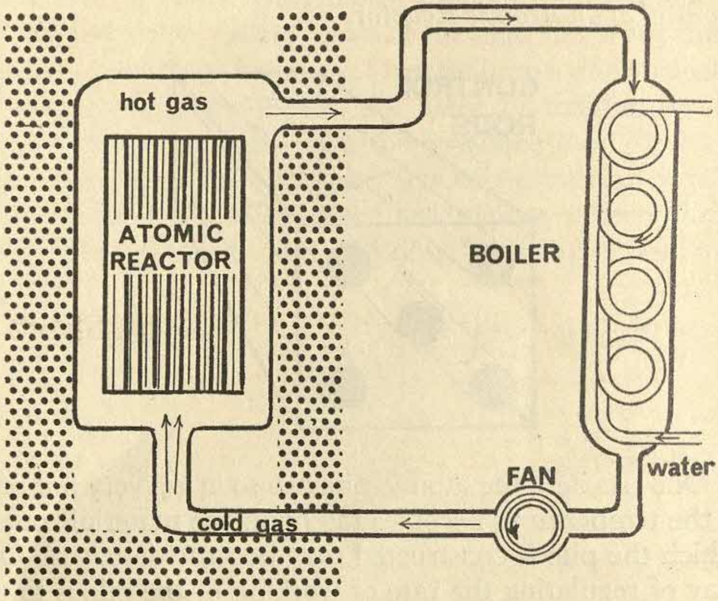
Control of an Atomic Reactor



Once started, the atomic pile can soon get very hot and, if the temperature becomes too high, the materials out of which the pile is constructed may become damaged. One way of regulating the rate of working of the pile is to use bars of metal called *control rods*. The rate at which heat is produced depends on the rate at which uranium atoms are split, and this depends on the flow of neutrons. Most elements absorb neutrons, but some, like boron and cadmium, are particularly effective at swallowing them up. By inserting rods of boron or cadmium into an atomic pile, any desired proportion of neutrons can be absorbed and the rate of reaction slowed down accordingly.

NUCLEAR POWER

The heat given out by an atomic pile can be used to raise steam to drive turbines which will generate electricity. In most respects, an atomic power station is similar to the usual type of power station, the main difference being that, instead of coal-fired furnaces, an atomic reactor is used for producing the heat.



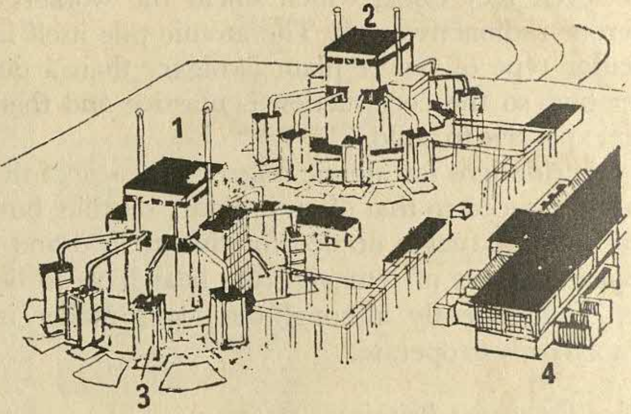
The diagram shows one type of atomic power plant, in which gas is made to circulate around the atomic pile, where it soon gets very hot. This heated gas is then pumped to a large vessel called the *boiler*. Here the hot gas flows round coils of water pipes to heat them, so that by the time the water reaches the end of its journey in the boiler it is converted to steam. Of course, the gas is cooled during this part of the process and so it has to be pumped back to the reactor chamber for re-heating, to be used again and again. Several different gases have been tried out for this purpose and it has been found that carbon dioxide, which is inexpensive, is suitable. As the gas is kept at high pressure, three or four times that of a motor-car tyre, the reactor chamber must be made of steel of about two inches in thickness. Outside this steel shell there are walls of concrete, about seven feet thick, which shield the workers from dangerous radioactive rays. The atomic pile itself in this particular type of power plant is bigger than a double-decker bus, so the construction is massive and therefore rather expensive to build.

In other designs for atomic reactors, the size of the pile has been reduced to that of an ordinary dustbin, but "enriched" atomic fuel is needed for this method and more complicated ways of removing the heat have to be employed. Consequently, although the pile is smaller, it may be just as costly to operate.

Nuclear Power for Britain

The wonderful atomic power stations, like those at Calder Hall in Cumberland, and Dounreay in Scotland, are really large-scale experiments for trying out nuclear reactors for supplying heat to steam turbines which generate electricity and, at present, they are rather costly to run. Electricity is still produced much more cheaply by using coal or oil. However, the prices of these fuels continue to increase and, as nuclear reactors become more efficient, the day will approach when most of the world's power will be obtained from nuclear sources.

The first *commercial* nuclear power station in the world, at Berkeley in Gloucestershire, has already demonstrated the confidence of British industry that atomic power can be produced at a competitive price. The Berkeley power station (see the diagram on the next page) has resulted in greatly increased efficiency. There are two reactors, each contained in cylindrical pressure vessels fifty feet in diameter and three inches thick (1 and 2 in the diagram). The steam-raising plant (3), arranged around each reactor, feeds superheated steam to the turbine hall (4), where



An artist's impression of the new nuclear power station at Berkeley, Gloucestershire

the electricity is generated. The output of the reactors will be about three times that expected from Calder Hall.

Nuclear Power Station under Ice

The world's northernmost nuclear power station has been installed at an underground village deep below Greenland's stormswept ice-cap. The reactor provides light and heat at Camp Century for 200 American scientists who are studying the structure of the ice-cap as well as making detailed weather observations.

In chambers dug out of the ice are a church, cinema, library, restaurant and club rooms which are all kept heated and well lit. In addition, the reactor enables vegetables to be grown while Arctic gales howl over the roof of the camp.

About 2,250,000 gallons of oil would be needed to produce the same amount of power with diesel motors. About 2 lb 3 oz of uranium will produce the same power as 20 tons of oil. A year's supply of uranium can be flown to Camp Century by a helicopter.

Nuclear Power for Transport

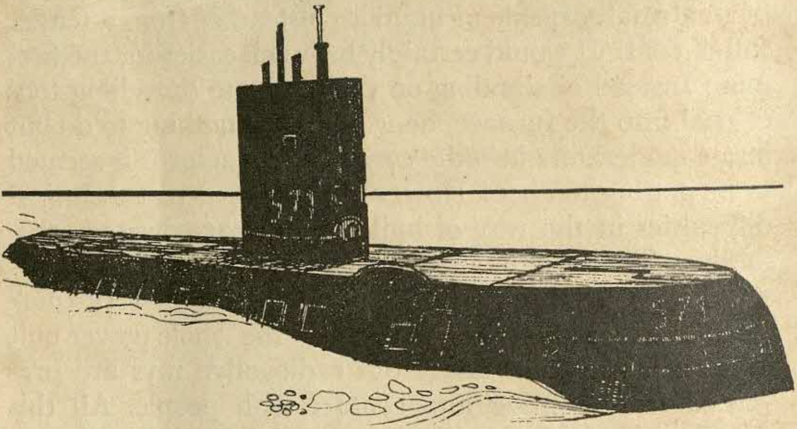
A piece of uranium about the size of a match-box is capable of producing as much energy as two or three railway truckloads of best grade coal. This being so, would it not be a great advantage for the steam locomotive of a train travelling from London to Scotland to obtain its power from a small capsule of uranium instead of from a tender full of coal? It would certainly be much easier for the fireman. Instead of standing on the footplate shovelling tons of coal into the furnace, he would have nothing to do but insert moderators into the core of the reactor if it seemed to be getting too hot! However, there are great technical difficulties in the way of building nuclear-powered locomotives. The walls of a reactor vessel must be able to withstand high pressures and are usually made of very thick steel. There is also the need to shield the whole power unit in such a way that dangerous radioactive rays are prevented from coming into contact with people. All this would make the locomotive very costly to build, so that as yet it has not been considered worth while to change to nuclear-powered engines.

The same considerations have postponed the introduction of nuclear-powered aircraft. In addition, the designers have to remember that if such an aircraft should crash there would be the danger of radioactive material escaping into the atmosphere. In spite of these problems, scientists and aircraft engineers are confident that nuclear-powered jet planes will become a reality.

And who knows, perhaps the motor cars of the future will not need to pull up at petrol stations for fuel, for they may be nuclear-powered, too!

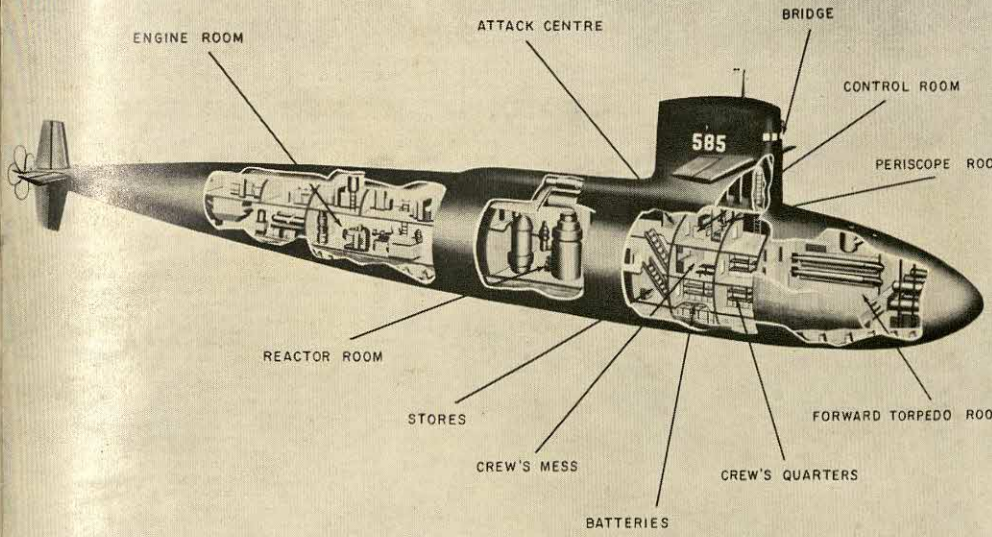
Atomic Ships

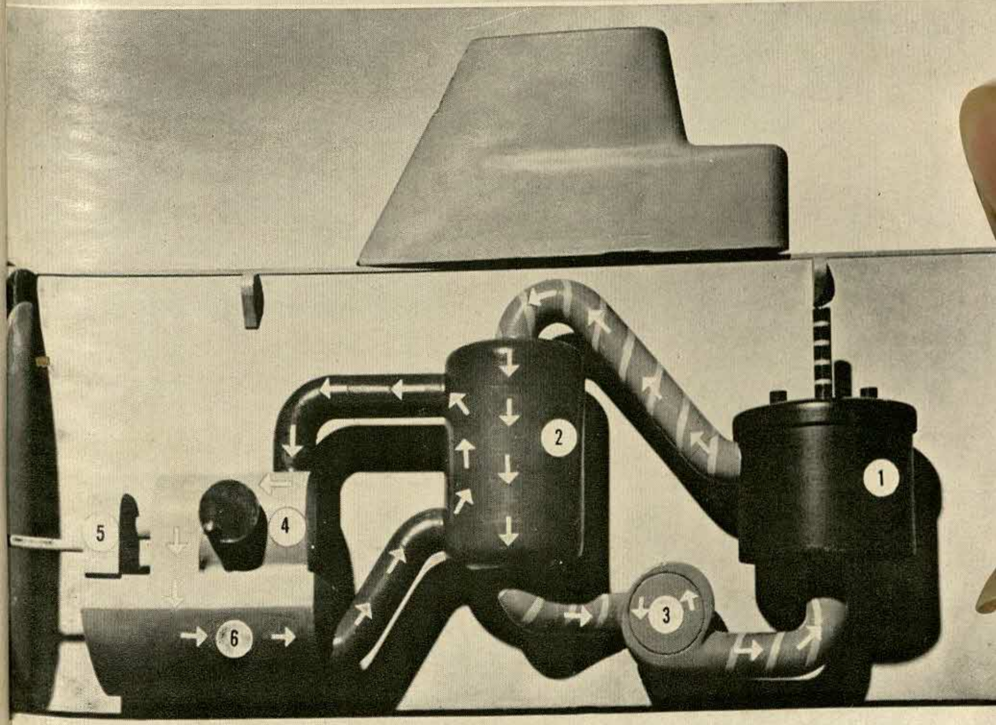
It is easier to overcome problems of shielding and weight in ships than in railway locomotives and aircraft. Also, since ships on long voyages have to stop and lose time for refuelling, and since much valuable cargo space has to be taken up by fuel bunkers, it has been thought that atomic ships would be a commercial proposition.



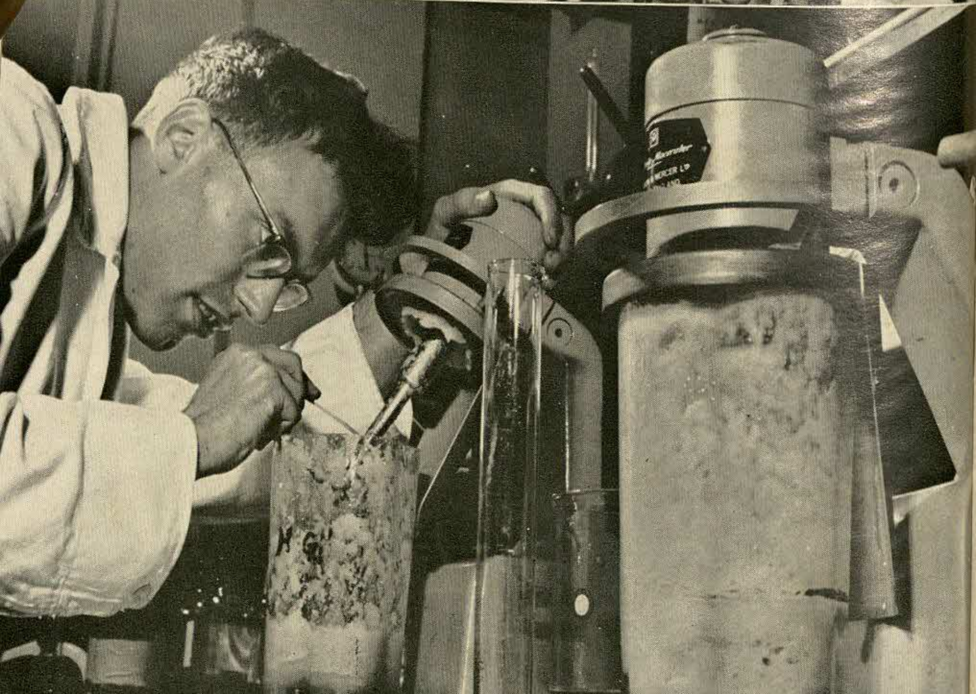
The first atomic ships to be built were submarines because, of all craft, they derive the greatest advantage from nuclear propulsion. A submarine driven by oil requires refuelling very often and this restricts its movements. Moreover, oil engines need air and so the submarine has to surface periodically to renew its air supply. The introduction of nuclear reactors for submarine propulsion has overcome both of these operational difficulties. The first nuclear-propelled vessel to be built was the American submarine *Nautilus*, which steamed 60,000 miles on her first fuel charge. The first British nuclear submarine was launched by Queen Elizabeth II in October 1960. The American

(*Above*) U.S.S. NAUTILUS, *the first nuclear-powered submarine*
(*Below*) A MODEL OF NAUTILUS'S MOTOR


ENGINE ROOM
ATTACK CENTRE
BRIDGE
CONTROL ROOM
PERISCOPE ROO
585
REACTOR ROOM
STORES
CREW'S MESS
BATTERIES
CREW'S QUARTERS
FORWARD TORPEDO ROO


1
2
3
4
5
6

W
X
Z



and British navies are building other nuclear submarines, and in Russia a nuclear-powered ice-breaking ship has been brought into service. Much experience has been gained from *Nautilus* and other nuclear-powered vessels, so that this kind of propulsion is now being extended to ordinary surface ships. Oil companies are showing great interest in the possibility of building super-tankers powered by nuclear reactors. There seems to be no doubt that it will be only a matter of time before nuclear power will oust the conventional fuels for large ocean-going vessels carrying cargo or passengers.

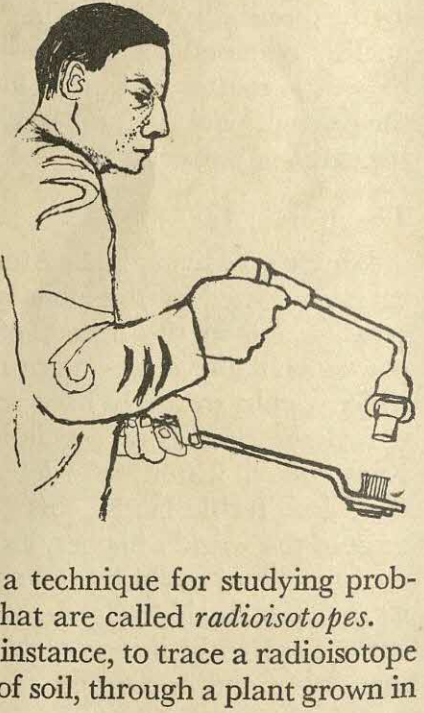
The Atomic Age

We are now living in the Atomic Age: if the tremendous energy released by the atom is used wisely, it will be the greatest age in the history of mankind. The unlimited power available in the atom makes engineering projects which would formerly have seemed impossible now well within the bounds of possibility. Men should be able to bring enough water to the desert areas of the world to turn them into fertile lands: this should see the alleviation of most of the world's hunger. Extensive use of nuclear-powered machines could release men and women all over the world from much drudgery and long hours of work. There could be greatly increased leisure for all people, giving more time and opportunity for travel and study. People and nations could have more time to get to know and understand each other, and to learn to work together.

EXAMINING INSTRUMENTS (*Above*)

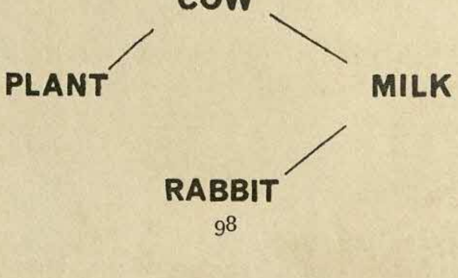
A ROUTINE TEST FOR RADIOACTIVE CONTAMINATION (*Below*)

XI. RADIOISOTOPES



Ordinary phosphorus occurs in the ground in the form of phosphates and, as every gardener knows, plants soon begin to suffer if there is a lack of this element in the soil. How does the plant use the phosphorus? What happens to it if the plant is eaten by an animal? If the animal gives milk, will the milk contain phosphorus? Scientists have developed a technique for studying problems like these by using what are called *radioisotopes.*

It has been possible, for instance, to trace a radioisotope of phosphorus in a sample of soil, through a plant grown in



the soil, through a cow fed on the plant, and finally through a rabbit fed on milk obtained from the cow. In order to understand how this has been done, we shall have to know something about the special properties of radioisotopes and how they may be detected.

WHAT ARE RADIOISOTOPES?

Radioactive isotopes, or radioisotopes, as they are called, are atoms that give off radiation and so gradually change to become other kinds of atoms. This radiation makes it easy to detect their presence and therefore they are valuable for research of all kinds.

A few radioisotopes occur naturally, as in uranium. However, most radioactive isotopes now used for research are artificially made by bombarding atoms with atomic particles.

The first artificial radioisotopes were made during the 1930s by such atom-smashing machines as cyclotrons.[1] Ordinary elements when bombarded with alpha-particles or neutrons are changed in their basic atomic structures. In other words they become different elements. It is the process of *transmutation*, which was the dream of the alchemists who tried to change cheap metals into gold. Modern scientists have exceeded this dream by changing ordinary elements into substances far more valuable than gold!

THE GEIGER COUNTER

Radioisotopes differ from non-radioactive substances in that they constantly emit tiny charged particles and so-called *gamma-radiation*. A careful study of radioactivity has shown that the charged particles consist of alpha-par-

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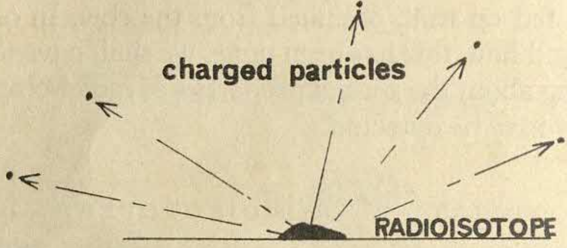
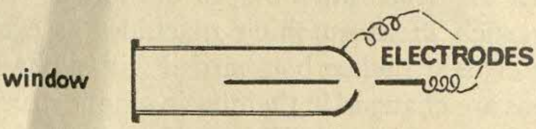
[1] See pp. 69–71.

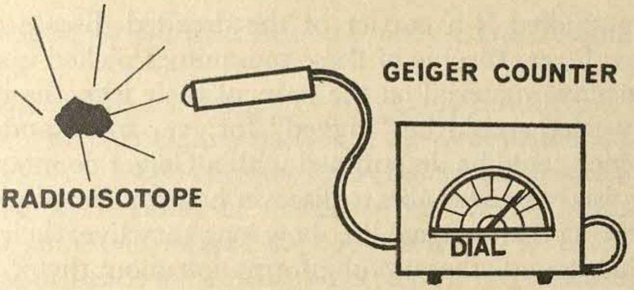


ticles and electrons, which produce an electrical effect when they pass through matter. A Geiger counter is an instrument which makes use of this fact to detect the presence of radioactive rays and to measure the number of particles being emitted in a given time.

Geiger-Müller Tube



One form of Geiger counter is the Geiger-Müller tube, which usually consists of a gas-filled tube made of glass which can be connected to an electric circuit. Particles entering the tube through a window of thin material such as mica bring about a change in the flow of current in the circuit. These fluctuations in the flow of current are recorded by a detecting device. One type of detector counts the impulses and shows the number on a dial; another type of detector gives out clicking sounds through a loudspeaker. The "click, click" type of Geiger counter is very convenient for prospectors and others who search for the



presence of radioactivity, but the "dial" is more suitable when an accurate count of radioactive particles is required.

RADIOISOTOPES FOR RESEARCH

Radioisotopes have provided a wonderful new tool for the research worker. Let us take an example from fruit growing. The growth of apple trees is impaired by certain fungi which grow on the bark and other parts of the tree. Mercury compounds are most effective in destroying fungi but are also very poisonous. Some Danish scientists have experimented with radioisotopes of mercury to find out how much mercury would be left on plants after spraying them with fungicides containing mercury. In their experiment they mixed radioactive mercury with ordinary mercury used in the fungicide. The chemical reactions of the radioactive atoms are precisely the same as the non-radioactive atoms, but their presence, even in the smallest quantities, can be detected by a Geiger counter.

It was found that apples sprayed once only with mercuric fungicides retained a certain proportion of mercury, nearly all of which was in the outermost layers of the apple peel.

Another example of the use of radioisotopes in research is a project in Nigeria which aims at finding out more about the life and habits of the mosquito. The species of mosquito being studied is a carrier of the dreaded disease called yellow fever. If some of these mosquitoes picked up some radioactive material on the hairs of their legs, the insects in question would be "tagged" for ever more and their presence could be determined with a Geiger counter. The scientists have been able to discover how far the mosquitoes fly during their normal life, how long they live, their feeding habits and other useful information about them.

Radioisotopes in Medicine

Ever since Pierre and Marya Curie discovered the healing properties of the radioactive rays of radium, scientists and doctors have been on the look-out for other materials with similar properties. This is important because the world's supply of radium is limited and a time will come when it will all be used up.

Now radioisotopes are being used in medicine in two important ways: they are used as tracers to find the actual place of the disease and also as agents to attack the disease by radiation, just as X-rays and radium radiation are used. The nuclear reactors at Harwell in England and Oak Ridge in the United States are kept busy making radioisotopes to send to all parts of the world for medical and other purposes.

All radiations from radioactive isotopes have the property of damaging the cells which make up living things and it is very dangerous for human beings to be exposed to radioactive rays. This property can be used to advantage in medicine because radioactive rays can be made to destroy diseased tissue in the body. Very small quantities of radioisotopes are injected into the centre of the diseased part and they have proved most effective in many cases. There are several ways of administering the radioisotopes: they can be injected into the blood-stream, taken through the mouth, or beamed into the body from outside, like X-rays.

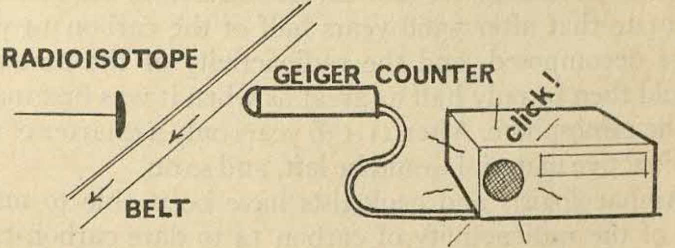
Radiocobalt, an isotope of the metal cobalt, has been found to be particularly useful for the treatment of certain diseases. It is much cheaper than radium and easier to use than X-rays. It may be machined into various shapes to fit into different parts of the body or it may be made into needles or beads to be placed directly into the diseased tissue. Radiocobalt has been used extensively for the treatment of cancer. Another useful radioisotope for the treatment of disease is radiogold which, oddly enough, is one of the least expensive of radioisotopes.

Radioiodine, radiophosphorus, radioiron and radiocarbon are some of the most important of the isotopes used in medicine. Radiophosphorus has been used to combat certain blood diseases and to treat tumours of the brain.

Industrial Uses of Radioisotopes

The applications of radioisotopes to industry are limitless and it is only possible to mention here a few of the uses to which they have been put.

One very ingenious device uses radioisotopes to measure thickness. A radioisotope is placed on one side of a moving belt of material, such as paper or stripmetal, and a Geiger counter is placed on the other side. The amount of radio-



activity measured by the Geiger counter indicates the thickness of the sheet and variations can be corrected automatically.

Other uses include the finding of leaks in pipes even when these are behind walls, tracing the flow of liquids through pipe-lines, measuring wear on the cutting edge of machine tools, detecting invisible flaws in metals, hardening rubber, speeding-up the manufacture of certain plastic materials and the study of the effectiveness of certain preservatives on telephone posts.

Dating Objects by Use of Radioactive Carbon

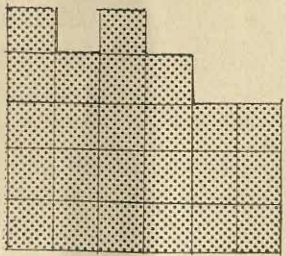
A very interesting application of radioactivity is the determination of the age of materials containing carbon (e.g. wood, coal, skin, or other plant or animal remains) by measurement of their radioactivity due to carbon 14. This radioactive isotope of carbon is made at a steady rate in the upper atmosphere. It becomes oxidised to carbon dioxide gas which gradually becomes mixed with the non-radioactive carbon dioxide in the atmosphere. Carbon dioxide is absorbed by plants and, in turn, animals eat the plants. When a plant or animal dies, the amount of radioactive carbon dioxide in its tissues can be determined by measuring the radioactivity of a sample of carbon obtained from it. By means of very careful experiments on the rate of decay of radioactive carbon, scientists have been able to estimate that after 5568 years half of the carbon 14 will have decomposed, and the radioactivity of the material would then be only half as great as when it was first made in the atmosphere. After 11,136 years only a quarter of the radioactive material would be left, and so on.

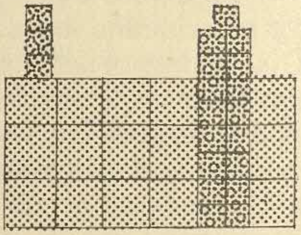
Archaeologists and geologists have been able to make use of the radioactivity of carbon 14 to date carbon-containing substances which may be very old, such as specimens of wood from a buried forest or bones or other remains from camping sites of long ago.

No one can predict to what other uses radioisotopes may be put in the future but it is safe to say that they will continue to be very important servants of man.

XII. ATOMS AND MOLECULES

A MOLECULE is the smallest particle of a substance capable of existence; for example, the smallest piece of chalk capable of existing as chalk is a molecule of it. If a molecule of chalk were broken down into its constituent carbon, calcium and oxygen atoms, it would cease to be chalk, just as a house built of blocks ceases to be a house when it is reduced to piles of different building blocks.



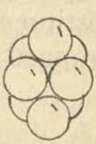


Now, it is possible to build a model of a house out of building blocks which are all of the same kind, or out of several different kinds of blocks. For instance, the blocks for the walls could be either identical with those for the roof and chimney or of a different colour and shape. Similarly, molecules of substances can be made up of all the same kind of atoms or of several different kinds of atoms.

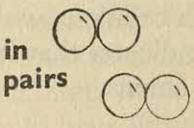
ELEMENTS

On page 30 it was stated that everything in the universe, the rocks, the oceans, the air, plants and animals, is made up out of about one hundred elements. A complete table of these elements is given on pages 112–13.

One way of defining an element would be to say that a molecule of an element, iron, for example, is made up of only one kind of atom. A hydrogen molecule is made up of hydrogen atoms, an oxygen molecule is composed of oxygen atoms, a sulphur molecule of sulphur atoms. Experiments have indicated that sulphur vapour contains molecules made up of bundles of eight sulphur atoms, and that oxygen molecules contain just two oxygen atoms each.



SULPHUR (S_8)



OXYGEN (O_2)

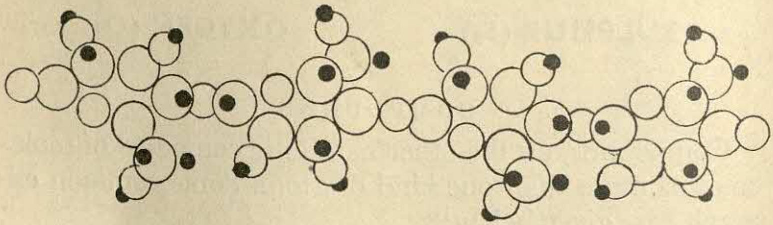
COMPOUNDS

Compounds, on the other hand, are composed of molecules of more than one kind of atom. Some common examples are given below:

Compound	*Constituent atoms*	*Formula*
water	2 hydrogen atoms, 1 oxygen atom	H_2O
carbon dioxide	1 carbon atom, 2 oxygen atoms	CO_2
ammonia	1 nitrogen atom, 3 hydrogen atoms	NH_3
copper sulphide	1 copper atom, 1 sulphur atom	CuS

Simple diagrams which help us to imagine molecules of compounds were devised by John Dalton (see pp. 37–38), but it is important to remember that atoms of different elements are often very different in size, and that the forces which hold the atoms together in the molecule depend on the atoms themselves.

Of course, molecules are very small (millions and millions would be needed to make up a pin-head), and much of the information we have about them has been obtained by studying the way in which substances react with each other. However, there is also direct evidence for the structures of some of the largest molecules. In recent years, work with X-rays has helped to confirm the way in which certain large molecules are made up. X-ray photographs, obtained by passing X-rays through substances and then allowing them to fall on a photographic plate, gave patterns of spots or rings which suggested that the substances were made up of rows and layers of atoms in repeating patterns. Very elaborate study of the patterns obtained by passing X-rays through cellulose, which is the main constituent of cotton wool, indicates that its molecules are arranged end to end in long chains.



Research into the size and shapes of molecules of various substances has shown that many substances which form fibres, such as cellulose, rubber, nylon and certain plastics, have their molecules in long chains.

MIXTURES AND COMPOUNDS

Although it is quite possible for chemical compounds like common salt, chalk, water and carbon dioxide to be obtained chemically pure, ordinary substances like wood, tap water, cheese, sand, clay and fruit juice are made up of many different chemical compounds all mixed up together. Ordinary air, for example, contains oxygen, nitrogen, carbon dioxide, water vapour and very small amounts of other gases. The salt obtained from sea-water or from salt mines contains potassium chloride, magnesium chloride and many other compounds mixed in with the main constituent, sodium chloride.

A FAMILY TREE OF MATTER

If we tried to make a "family tree" for a piece of ordinary matter, e.g. a handful of garden soil or a slice of bread, or anything at all, the first step would be to find out the different chemical substances of which it was composed. Each chemical substance in the piece of matter would be made up of vast numbers of similar molecules, and each molecule of a number of atoms, which might be of several different kinds. At one time, we should have finished the family tree when we had reached the atoms out of which all matter is constructed, but we now know that the atoms themselves can be broken down into their fundamental particles—electrons, protons and neutrons.

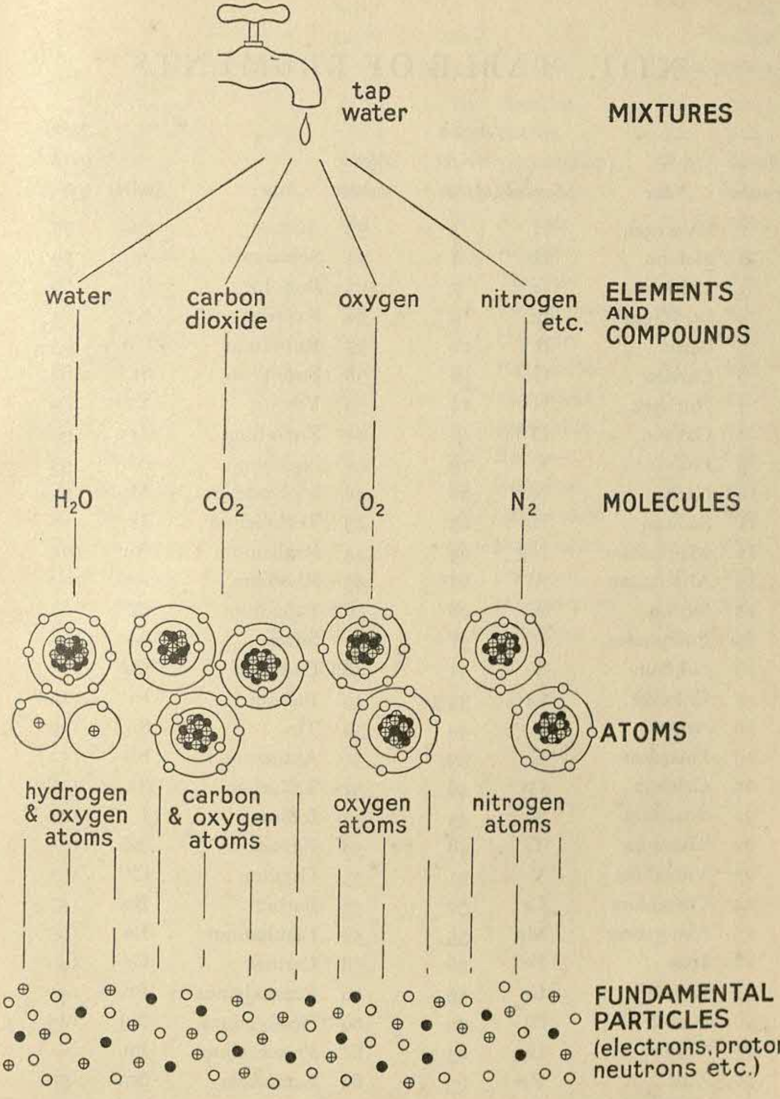
Ordinary tap water is a relatively pure substance and yet it contains quite a number of chemical substances. A drop of water from the kitchen tap at home contains the following chemical substances:

> water, carbon dioxide, nitrogen, oxygen, calcium bicarbonate, magnesium bicarbonate and other substances.

Each one of these chemical substances is made up of millions of molecules: water of water molecules, carbon dioxide of carbon dioxide molecules, nitrogen of nitrogen molecules and so on. Water molecules are made up of atoms of hydrogen and oxygen, carbon dioxide molecules of carbon atoms and oxygen atoms, and nitrogen of nitrogen atoms. All these different kinds of atoms are composed of electrons, protons and neutrons.

HOW THE UNIVERSE IS MADE

There is a wonderful and infinite variety of substance in the universe: incredible diversity of living things, uncounted chemical compounds in the rocks and minerals which compose the crust of the world, other substances in the oceans and seas, the different gases of the atmosphere and of the space beyond. It is an astounding fact that all these things are made up from about one hundred different elements; even more astounding that the atoms and molecules of these elements are all made of the same fundamental particles.


tap water
MIXTURES
water
carbon dioxide
oxygen
nitrogen etc.
ELEMENTS AND COMPOUNDS
H_2O
CO_2
O_2
N_2
MOLECULES
ATOMS
hydrogen & oxygen atoms
carbon & oxygen atoms
oxygen atoms
nitrogen atoms
FUNDAMENTAL PARTICLES (electrons, protons, neutrons etc.)

XIII. TABLE OF ELEMENTS

Atomic number	*Name*	*Symbol*	*Atomic weight (approx.)*
1	Hydrogen	H	1
2	Helium	He	4
3	Lithium	Li	7
4	Beryllium	Be	9
5	Boron	B	11
6	Carbon	C	12
7	Nitrogen	N	14
8	Oxygen	O	16
9	Fluorine	F	19
10	Neon	Ne	20
11	Sodium	Na	23
12	Magnesium	Mg	24
13	Aluminium	Al	27
14	Silicon	Si	28
15	Phosphorus	P	31
16	Sulphur	S	32
17	Chlorine	Cl	35·5
18	Argon	A	40
19	Potassium	K	39
20	Calcium	Ca	40
21	Scandium	Sc	45
22	Titanium	Ti	48
23	Vanadium	V	51
24	Chromium	Cr	52
25	Manganese	Mn	55
26	Iron	Fe	56
27	Cobalt	Co	59
28	Nickel	Ni	59
29	Copper	Cu	63·5
30	Zinc	Zn	65
31	Gallium	Ga	70
32	Germanium	Ge	73
33	Arsenic	As	75
34	Selenium	Se	79
35	Bromine	Br	80
36	Krypton	Kr	84
37	Rubidium	Rb	85·5
38	Strontium	Sr	88
39	Yttrium	Y	89
40	Zirconium	Zr	91
41	Niobium	Nb	93
42	Molybdenum	Mo	96
43	Technicium	Tc	—
44	Ruthenium	Ru	102
45	Rhodium	Rh	103
46	Palladium	Pd	107
47	Silver	Ag	108
48	Cadmium	Cd	112
49	Indium	In	115
50	Tin	Sn	119
51	Antimony	Sb	122
52	Tellurium	Te	128
53	Iodine	I	127
54	Xenon	Xe	131
55	Caesium	Cs	133
56	Barium	Ba	137
57	Lanthanum	La	139
58	Cerium	Ce	140
59	Praseodymium	Pr	141
60	Neodymium	Nd	144
61	Promethium	Pm	—
62	Samarium	Sm	150
63	Europium	Eu	152
64	Gadolinium	Gd	157

Atomic number	*Name*	*Symbol*	*Atomic weight (approx.)*	*Atomic number*	*Name*	*Symbol*	*Atomic weight (approx.)*
65	Terbium	Tb	159	85	Astatine	At	210
66	Dysprosium	Dy	162·5	86	Radon	Rn	222
67	Holmium	Ho	163·5		(Emanation)	(Em)	
68	Erbium	Er	168	87	Francium	Fr	223
69	Thulium	Tm	169	88	Radium	Ra	226
70	Ytterbium	Yb	173	89	Actinium	Ac	—
71	Lutecium	Lu	175	90	Thorium	Th	232
72	Hafnium	Hf	179	91	Protoactinium	Pa	231
73	Tantalum	Ta	181	92	Uranium	U	238
74	Tungsten	W	184	93	Neptunium	Np	237
75	Rhenium	Re	186	94	Plutonium	Pu	239
76	Osmium	Os	191·5	95	Americium	Am	241
77	Iridium	Ir	193	96	Eurium	Em	242
78	Platinum	Pt	195	97	Berkelium	Bk	249
79	Gold	Au	197	98	Californium	Cf	249
80	Mercury	Hg	201	99	Einsteinium	Es	254
81	Thallium	Tl	204	100	Fermium	Fm	255
82	Lead	Pb	207	101	Mendelevium	Md	256
83	Bismuth	Bi	209	102	Nobelium	No	253
84	Polonium	Po	210				

XIV. MEANINGS OF SOME SCIENTIFIC TERMS

ALPHA-PARTICLE: Alpha-particles are given off by radioactive elements such as uranium. A single alpha-particle has a mass about four times that of a hydrogen atom and is doubly positively charged: it can therefore be regarded as the positive part of a helium atom.

ATOM: the smallest particle of an element which possesses the properties of the element. An atom is composed of a positively-charged nucleus and a number of electrons which travel in orbits around the nucleus.

BETA-PARTICLE, CATHODE-RAYS, see ELECTRON.

CYCLOTRON: a machine used by scientists to shoot particles into atoms at very high speeds. Other atom-smashing machines which have been developed from the cyclotron are synchrotons, cosmotrons and bevatrons.

CHEMISTRY: that part of science that studies alterations and changes which result in new substances being formed. Chemistry studies such subjects as changing of iron into rust, the action of acids on metals and other substances, the formation of soap from fats and alkalis.

ELECTRON: An electron is one of the particles which help to constitute an atom. An electron has 1/1837th the mass of the smallest atom and is negatively charged. Streams of electrons as obtained in discharge tubes (see pp. 40–2) are called cathode-rays. Beta-particle is another name for an electron, usually used when electrons are emitted by a radio-active element. See also NEUTRON and PROTON.

Element : There are about one hundred different kinds of matter or elements out of which the universe is made. These different elements combine together to form compounds, e.g. the elements calcium, carbon and oxygen combine together to form chalk.

Energy : the ability to perform work.

Fission : the splitting of the nucleus of an atom into two or more parts. The fission of uranium leads to the release of a considerable amount of energy.

Fundamental Particles : the various particles which make up atoms, such as protons, neutrons and electrons.

Fusion : the joining together of atoms. Sometimes when two small atoms join forces to form a larger atom, an amount of energy is "left over". Therefore fusion, as well as fission, gives rise to the release of atomic energy.

Gamma-rays : rays given out by radioactive substances, similar to X-rays or radio waves.

Geiger Counter : an instrument which detects the presence of charged particles. The arrival of each particle creates a disturbance which can be amplified until it can be registered on a Geiger counter, by a clicking sound or by a mechanical counting device.

Helium : a gas found in very small amounts in air. Only hydrogen atoms are lighter than those of helium.

Hydrogen : an inflammable gas, the lightest of the elements.

Ionisation Chamber : a box containing a vapour. Each charged particle entering the box alters the vapour by giving it a burst of energy. The change in the conducting power of the vapour gives a measure of the energy brought into the box by the charged particles.

ISOTOPE : When an element has more than one kind of atom, the different forms are called isotopes of the element. Although the weights of the isotopes of an element may be different, their chemical properties are exactly the same.

MAGNETIC FIELD : A magnetic field which exists between the poles of a magnet interacts with moving charged particles in such a way that they are deflected perpendicular to the direction of motion and the field.

NEUTRON : one of the particles which make up atoms. Unlike protons and electrons, neutrons are electrically neutral. See also ELECTRON and PROTON.

NUCLEUS : the centre of an atom; sometimes called the core or kernel of an atom.

PHYSICS : the study of energy in all its forms (heat, light, sound, electricity and the forces which hold atoms together).

PROTON : a positively-charged particle which, like the neutron and the electron, is an important constituent of atoms. A proton has approximately the same mass as a neutron and it carries a positive charge. See also ELECTRON and NEUTRON.

RADIOACTIVE : the state in which some naturally occurring elements, such as radium and uranium, are when they give out small, electrically charged particles and energy. Radioactive elements, like radium, gradually change into other elements. Scientists are now able to make radioactive many ordinary elements, such as iron or iodine, and these are valuable in treating diseases as well as having many other uses.

RADIUM : a metal which is many times heavier than iron. It is radioactive and keeps sending out alpha-particles until it finally changes into the very unreactive gas, radon.

REACTOR : the name given to an atomic pile which is working and producing energy. Usually, artificial radioactive elements are produced during the operation of a nuclear reactor and so sometimes the main work of the reactor is to provide radioactive material.

TRANSMUTATION: It is possible to change the structure of some atoms by shooting charged particles into them; this is called transmutation. Often such atoms lose their identity and become other atoms.

URANIUM: a very heavy metal which is naturally radioactive; it is the heaviest natural element. Like radium, uranium emits alpha-particles.

VOLT: an electrical unit. Voltage, or potential difference, may be regarded as the pressure which pushes the current through a wire.

X-RAY: a ray of energy which has the power of passing through objects which are not too dense. X-rays are similar in some ways to rays of light.

ZINC SULPHIDE SCREEN: a plate which emits light when bombarded with charged particles just as the "tube" of a television set emits light when bombarded with electrons. (A zinc sulphide coating on your T.V. tube would give you a green picture.)

XV. SOME ATOMIC SCIENTISTS

Of the great number of scientists from many different nations who have helped to discover the nature of atoms, the following are mentioned in this book:

Benjamin Franklin (1706–90), an American, whose experiments with electricity demonstrated that lightning and electricity obtained by rubbing things together are the same.

John Dalton (1766–1844), a Manchester schoolmaster. His idea of the existence of atoms offered an explanation of the regular way in which elements combine together to form compounds. Dalton imagined atoms to be solid, like very small billiard balls.

Wilhelm Conrad Röntgen (1845–1923), a German professor of physics, who reported in 1895 that he had discovered a new kind of rays, which he called X-rays.

Henri Becquerel (1852–1908), a professor in Paris. His experiments with X-rays led to the discovery of radioactivity.

Albert Einstein (1879–1955), born in Germany. He acquired Swiss nationality, but became a United States citizen in 1941. Einstein developed the theory of the equivalence of mass and energy (meaning that matter can be transformed into energy, as in an atomic bomb or atomic pile).

Joseph John Thomson (1856–1940), a professor of physics at Cambridge University whose work with cathode rays demonstrated that electricity is made up of charged particles, which he called electrons.

Marya (1867–1934) and Pierre Curie (1859–1906). Marya was born in Poland but came to Paris to study at the university there. Later, she became the wife of Pierre Curie, another brilliant young scientist, and together they made many remarkable discoveries. Their most outstanding achievement was the discovery of the wonderful element called radium.

ERNEST RUTHERFORD (1871–1937) worked at Manchester and later became a professor at Cambridge University. A series of brilliant experiments enabled him to put forward the idea that atoms have a positively-charged nucleus with electrons arranged in orbits around each nucleus, like small solar systems.

JOHN COCKCROFT (*b.* 1897), trained as an engineer, became interested in atomic physics, and, together with E. T. S. WALTON (*b.* 1903), used an "atom-smashing machine" to speed up particles which could then be used to knock small pieces from atoms. Cockcroft and Walton succeeded in splitting some small atoms into two parts. Cockcroft was knighted in 1948; from 1946 to 1958 he was Director of the British Atomic Energy Research Establishment at Harwell. He became the first Master of Churchill College, Cambridge, in 1959.

JEAN FRÉDÉRIC JOLIOT (1900–58) and IRENE JOLIOT-CURIE (1897–1956). Irene, daughter of Marya and Pierre Curie, with her husband J. F. Joliot, found evidence for the existence of uncharged atomic particles, which were later named neutrons.

JAMES CHADWICK (*b.* 1891) was working at the Cavendish Laboratory in Cambridge on experiments similar to those of Irene Curie and J. F. Joliot when, in 1932, he suggested the existence of neutrons. He was knighted in 1945.

NIELS BOHR (1885–1962), a professor of physics in Copenhagen who advanced many valuable ideas on the ways in which atomic particles behave when they are shot into atoms. It was partly due to his encouragement that in 1938 Otto Frisch carried out his famous experiment which demonstrated uranium fission.

OTTO HAHN (*b.* 1879), born and educated in Germany. It was he who made the startling suggestion that when uranium absorbs a neutron it splits into two roughly equal fragments. He was awarded the 1944 Nobel Prize for chemistry.

OTTO FRISCH (*b.* 1904), born and educated in Vienna. He worked in Germany but left after Hitler came to power. In Copenhagen in 1938 he was able to demonstrate nuclear fission, following up an idea of Otto Hahn's.

XVI. HOW TO BECOME AN ATOMIC SCIENTIST

Atomic scientists work either for the Government as members of the Atomic Energy Authority, or for a private firm with interest in atomic energy, or perhaps in a university research department. As a rule, a university degree would be needed before one could apply for a position involving interesting research.

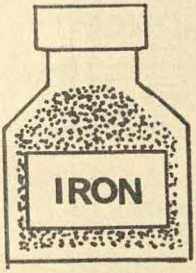
In order to obtain a place at a university, a boy or girl must first obtain his General Certificate of Education with five subjects at the ordinary level, and later three subjects at the advanced level. University regulations differ slightly, but, as competition for places is very keen, it is important to obtain good results in the G.C.E. examinations.

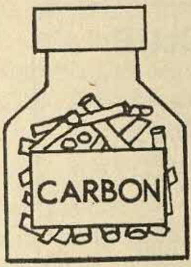
Some boys and girls may not be able to go straight to the university when they have finished school, but they still may be very keen to take up a career in science or engineering. There are a number of splendid apprenticeships offered by many scientific and engineering companies which would enable an apprentice to attend a technical college or university and go to work as well. Your local Youth Employment Officer can give you details of these apprenticeships.

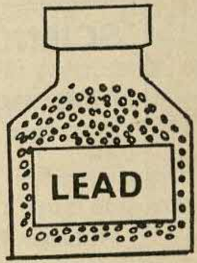
Of course, there is a great variety of jobs connected with atomic science for which a university qualification or G.C.E. advanced level certificates are not needed. Sometimes it is possible for young people to get posts as laboratory assistants or technicians with very little academic qualification.

XVII. THINGS TO DO

(1) *Make your own collection of elements*







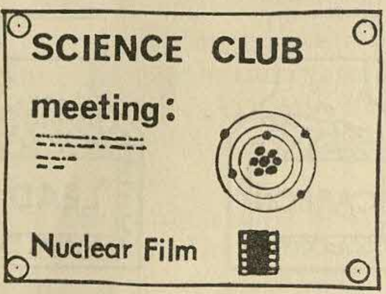
You will be surprised to find how many of the different elements you can collect together. Here are some elements which are fairly easy to obtain: iron, copper, aluminium, lead and carbon (charcoal, made by burning a piece of stick); sulphur and iodine can be bought quite cheaply from a chemist's shop. The different elements can be placed in labelled test-tubes or small bottles.

(2) *Atomic Scrap Book*

It is interesting to make a scrap book into which newspaper cuttings and photographs can be pasted. Pictures of the latest nuclear submarines and ships, accounts of new discoveries, news about conferences of scientists, and a complete list of all atomic bomb and hydrogen bomb explosions are some of the things which could go into the scrap book.

(3) *Wall Chart*

A boy or girl who is good at pen lettering could make an attractive wall chart for a classroom. This could take the form of a table of the elements with diagrams showing the structures of some atoms arranged around the outside of the chart.



(4) *Science Club*

If there is no science club at your school or youth club, see what can be done about it. You should be able to get interesting speakers and there are plenty of good scientific films which can be borrowed free of charge. A comprehensive list of films and filmstrips on chemistry and related topics is obtainable from The Royal Institute of Chemistry, 30 Russell Square, London, W.C.2. The list shows where to send for the films and where ones may be borrowed free of charge. Visits to power plants, chemical works, docks and airports might also be arranged. When arranging a visit of this kind, the best plan is to write to the Personnel Officer stating what you would like to see and how many would be in the party. It would be helpful to state the ages and special interests of persons in the group.

NOTES ON THE PHOTOGRAPHS

Frontispiece—PLUTO, a nuclear reactor used for experimental work. This nuclear reactor at Harwell in England was designed and built by the Atomic Energy Authority for experimental purposes. It contains uranium fuel. The scientists in the picture have removed the heavy shield cover at the top of the reactor and are loading the reactor with cadmium absorbers.

Facing p. 32—(*a*) Atoms for War. An atomic bomb is exploded; this atomic explosion was the eleventh in a series of tests carried out at Nevada in the United States in 1957.
(*b*) Atoms for Peace. This nuclear reactor at Dounreay in Scotland came into operation in November 1959. The nuclear reaction in the core produces heat and neutrons. The heat is removed by circulating liquid metal. The reactor and part of the heat exchanging circuit are installed in a concrete vault within a huge steel sphere (the ball-like structure in the middle of the picture).

Facing p. 33—BEPO (British Experimental Pile Zero Energy) at Harwell. BEPO, another reactor used primarily for research at Harwell, contains uranium fuel and is moderated with graphite. It produces neutrons. Materials placed in the reactor are bombarded with these neutrons and often artificial radioisotopes are produced. The men in the picture are loading a large tube into the core of the reactors. Later, some of the special materials to be tested will be placed in this tube.

Facing p. 48—Determination of the rate of flow of blood from one wrist to the other. A radioactive isotope is injected in one wrist and the counter is placed over the other. The doctor carrying out the experiment will measure accurately the time from the moment of the injection to the moment when the counter detects the presence of radioisotopes in the other wrist of the patient. Experiments like these help us to gain a better understanding of the workings of the human body.

Facing p. 49—Experiments with plants using radioisotopes. The scientist in the photograph is a biochemist. He is spraying the plants with radioactive dust in order to find out how they will be affected. The result of this research has shown that radioactive material given out by certain types of atomic bombs could destroy crops and so deprive a nation of its food supply.

Facing p. 96—(*a*) The first nuclear-powered submarine, U.S.S. *Nautilus.*

(*b*) A model of the nuclear-powered motor of the submarine *Nautilus* showing its main working parts. In the nuclear reactor (1), the splitting atoms of uranium-235 give out great heat which is carried to the boiler (2) by water kept under pressure and circulated by a pump (3). Under great pressure, the water does not change into steam and is allowed to reach a temperature high enough to keep the boiler generating steam. The steam goes from the boiler to the turbine (4) and drives the submarine by turning the propellers through a reduction gear (5). Exhaust steam from the turbine goes to a condenser (6) where it becomes water and is returned to the boiler for reheating.

Facing p. 97—(*a*) The scientists and workers in this picture are examining instruments in a nuclear reactor which is in danger of heating up too quickly. Some of the men are wearing protective clothing made of plastic material which would give protection against contamination with radioactive substances.

(*b*) This scientist is carrying out a routine test in the laboratory on various foods (milk, vegetables, meat, etc.) which may conceivably be contaminated with radioactive material.

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